STATE OF NEW JERSEY

Department of Conservation and Development

Report on Water Resources of the State and Their Development

HAZEN, WHIPPLE & FULLER
CIVIL ENGINEERS
30 EAST 42nd STREET
NEW YORK CITY

1922

Presented by

Hazen, Whipple + Fuller, Civil Engineers

March 1922.

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January 28, 1922.

To the Board of
Conservation and Development,
Trenton, New Jersey.

Gentlemen:

You have asked us to forecast the population and water requirements of the New Jersey Metropolitan District for a long time in the future, suggesting fifty years as an appropriate period, but not limiting consideration to it. You have also asked us to examine the water resources of the State in a broad general way to see, as far as we are able, how future requirements can best be met.

Your department undertook to co-operate with us in making this study by placing its resources at our disposal, and it is a pleasure to record that we have received promptly and fully every aid that could have been expected.

Your director, Mr. Alfred Gaskill, accompanied us on inspection trips to all the principal proposed sources and took the greatest interest in the studies.

We are especially indebted to Dr. Henry B. Kummel, Geologist of the Department, and to Mr. H. T. Critchlow, Hydraulic Engineer. We have also drawn frequently upon those connected with many of the thirty-three water works systems now operating in the Metropolitan District for data in regard to their systems, and we have found cordial co-operation, for which acknowledgement is made. In our office Mr. Malcolm Pirnie has devoted his time largely to collecting the field data and to studies, and several assistants from our force have aided in the work.

1. Outline and Summary

The water resources of New Jersey are great and conveniently situated. Taking everything into account, there is scarcely a state in the Union so favorably situated for providing the water supply of a great Metropolitan District. In saying this we have in mind

the quality and accessibility of the water that can be provided; clean and soft for domestic and industrial uses, and near at hand and high enough to be delivered by gravity, or mainly by gravity, in large volumes at relatively low costs.

The capacity of these splendid nearby sources is so great that if they are carefully conserved and developed they are sufficient for any requirements that can be reasonably anticipated. It will be shown in this report that, if there was a market for ten times the quantity of water now sold, it could be provided at reasonable rates.

There are several problems that must be met and solved. Among these may be mentioned:

First, the engineering problem of selecting the best sources and of deciding what dams, tunnels, reservoirs and other works will best serve to make them available;

Second, the problem of getting effective co-operation of the thirty-three separate authorities now operating water works systems in the Metropolitan District; or in the absence of such co-operation of finding some way of securing effective action in their behalf;

Third, the adopting and carrying through of a comprehensive policy of building and operating water works, and of securing control of necessary sites, and holding them for public water supply purposes to make sure that they are not diverted to other uses and lost.

This report is divided into several parts. The first is general in character and is a summary of those which follow. The second deals with water supply conditions and shows that 2,070,000 people in the Metropolitan District are supplied with 244 mgd. (million gallons per day) of water by thirty-three separate water works systems, and that the maintainable capacity of the sources now in use is estimated at 268 mgd. The margin of 24 mgd. is too small for safety.

The third contains a study of past and future growth in population and water consumption. Only time will tell what future growth will be; but it is considered prudent to provide for the needs of a population of 5,600,000 in the Metropolitan District in 1970. The quantity of water then to be provided from public water supply systems is estimated at 820 mgd.

In the fourth part are recorded the principal catchment areas now used, and those available for future use of the District, with certain statistics in regard to each, and to the reservoirs necessary to control them. The Morris Canal is mentioned as controlling

water rights that might be developed for water supply if navigation were abandoned; but the rights controlled are not large enough to make this a matter of first importance in the general problem.

In the fifth part are described in general terms the works considered suitable for developing the principal possible sources of water supply.

The Passaic Great Reservoir, to be formed by the construction of a dam at Little Falls, would completely equalize the flow of the river, and would furnish a continuous supply of water for all purposes including present supplies of 757 mgd.

It would eliminate all danger of floods like that of 1903, and like that which devastated Dayton in 1913, and to prevent the occurrence of which the Miami District is spending some fifty million dollars.

With the Great Reservoir development, a quantity of water, which for the present may be taken at 80 mgd. would be dedicated to manufacturing industries, and to keeping the channel of the lower river in good order, and a further 10 mgd. to replacing ground water supplies now drawn from Canoe Brook. This would leave 667 mgd. available for water supply.

The amount of water now taken from the Passaic River, including Canoe Brook, for public water supply, is 158 mgd.

The amount that can be developed by the best combination of existing works and the Wanaque Reservoir now building is about 240 mgd. To this may be added 33 mgd. obtainable by construction of the proposed Ramapo Reservoir.

The great Passaic Reservoir would thus produce 427 (or 394) mgd. of water not otherwise available.

If for any reason the Great Reservoir should not be built, then the river may be developed as far as advantageous by dams on its tributaries, but this should not be allowed to go to the extent of building works where the cost per million gallons of daily capacity is much above the general cost under other good projects.

It is then shown that certain northern streams can be combined into a single system by the construction of connecting tunnels. The central point in this system would be the Long Hill Reservoir to be constructed on the upper Passaic River above Millington. The quantity of water that can be collected by gravity in this reservoir is estimated at 619 mgd. The water would be excellent in quality, and it is near at hand so that short connections can be made with existing and future distribution systems in the Metropolitan District.

The Long Hill system would take 41 mgd. from the Passaic and 110 mgd. from the Raritan, and would reduce by these amounts the quantities otherwise available from these sources.

It is then shown that the Raritan can be developed to produce 414 mgd. (or 304 mgd. after the Long Hill system is built). In addition a connection may be made with the Delaware River and quantities of Delaware water supplied through it. The Raritan water is low in elevation and would have to be pumped, and this is a serious financial handicap to its use.

The Mullica and Wading Rivers in the southern part of the State could be made to produce 316 mgd. of excellent water, but the distance is great.

In the sixth part is presented in rough outline a consideration of the distribution of water, especially from the Long Hill Reservoir. A deep pressure tunnel is proposed extending through Newark to a terminal in Jersey City, a total distance of 19 miles, with connections to existing systems and to all parts of the district.

In the seventh part are presented some of the data and a summary of the more important calculations by which the quantities of water available from the various sources are determined.

Part eight relates to cost. The studies that have been made are general in character, and it has not been possible to extend them far enough to permit accurate cost estimates to be made. Rough general estimates are given and these serve for an economic comparison.

It is found that the Long Hill system, being made up of many small parts, can be built progressively in a way that is not possible for the others. To a growing community this progressive development is important, as it is more easily met within the financial limitations of its earlier stages.

From a water works standpoint, the Long Hill system is best both physically and financially, but when the advantages of flood protection and other general features of the Passaic Great Reservoir are considered, the advantages of the latter are so great that it may not hastily be put aside.

The ninth part briefly outlines a plan of procedure based on actual successful experience elsewhere, which, if followed, would secure the adequate gradual development of sources of water supply as needed, on a self-supporting basis, without permitting the work ever to become a burden on state funds.

The ground covered by this report is extensive. A general view of the whole of it is important. In such a general view details,

even large ones, must be passed. They are left for future study.

There is one matter that I wish to urge for your careful consideration. The water resources of the state are of the greatest importance. Future prosperity depends upon wise use of them. New York City is going two or three times as far, and spending correspondingly more money, because, as a result of state lines, it must go these great distances and spend these great sums to find, within its own boundries, suitable water sources. New Jersey, thanks to her location and natural resources may save a great part of such cost.

But the value in these splendid New Jersey resources can be realized only by use. If they are not used their value is not realized, and they are useful to the State only as fields and forests and as home sites, for which purposes they have no special value.

In one important respect water resources differ from other natural resources. A coal mine is depleted by use. Every ton taken out means a reduction in the store left. But water supplies are not decreased in capacity by use. If all the water is developed and used for a century there will not be one drop less available thereafter. It may even be put more strongly; if water supplies are developed and used the supply is sure to be, and to remain, available. If they are not developed and used, unsurmountable obstacles to their development may be found at some future time, due to the use of necessary sites for other purposes. With this in mind the use of water may actually increase the future amounts available.

This matter has been recognized in other parts of the country. San Francisco is developing a water supply that will not be needed for generations. This is done to be able to control with certainty at some future time the water that will be then needed. In the interval it is used to produce power which is sold to pay, or to aid in paying, carrying charges. In a similar way Los Angeles has anticipated future growth to an extent that is unusual in city water works, and is securing such income as it can by selling surplus water for irrigation to help pay carrying charges. Water used for irrigation in this generation will be part of the city's water supply in another.

It is suggested for your consideration that it may be possible for New Jersey, through some approved instrumentality, to acquire and develop and find some temporary use for the water from these magnificant supplies so as to hold them more certainly and make sure that the water will be available when it is finally needed.

Having great resources does not insure a supply of water. It makes a supply possible, but to realize the possibility there must be added strong, courageous, far-seeing and competent management. Without this natural resources might as well not exist.

2. Present Water Supply Conditions

In an area of 1,018 square miles, comprising the six counties of Bergen, Essex, Hudson, Middlesex, Passaic and Union are thirty-three water supply systems, serving 2,070,000 people. This area will be called the "Metropolitan District," or simply the "District."

The East Jersey Water Company sells water to several associated water companies, and to a number of municipalities. With this important exception, each of the water supply systems is dependent upon its own resources.

If the water were all pooled there would be enough available to meet ordinary requirements in years of average rainfall. In a dry year there would not be much margin. At present manufacturing is less active and the demand for water has fallen. When business improves the demand will increase and the margin will be wiped out. In any case the margin is not enough to cover any considerable growth. Surplus capacity is needed for safety in a rapidly growing community.

There is some loss of water by waste. Some of the thirty-three systems are only partially metered. Metering reduces waste. With complete metering the per capita consumption might be reduced from 118 to 100 gallons daily. This saving would cover the normal growth of five years.

Table No. 1 (Page 10), shows certain data in regard to the water supply business as it was actually carried out in the year 1920.

Principal Supplies

The facts in regard to the principal water supplies for the District are fully on record elsewhere, and it is only necessary to mention a few of the more important supplies in use, and now under construction, with a few comments that bear on their availability for use as parts of the permanent water supply system of the District.

(1) Newark draws an excellent supply from the Pequannock River, a tributary of the Passaic. Most of the catchment area of 63.7 square miles has been bought by the city to protect the quality of the supply. The area has been developed by the construction of several reservoirs. This development has gone so far that it will hardly pay to carry it further. The works as they stand will deliver 57 mgd. and the two pipe lines to the city will carry the full quantity.

TABLE No. 1

WATER SUPPLY SYSTEMS IN METROPOLITAN DISTRICT

	Average daily output gallons	Population	Services	Meters
Jersey City Water Dept......	60,800,000	298,079	39,247	9,223
Newark Water Dept..........	47,700,000	429,876	51,355	47,137
Hackensack Water Company.	29,400,000	355,000	44,903	43,036
East Jersey Water Co........	23,700,000	157,196	22,750	18,738
Elizabethtown Water Co.....	18,970,000	114,057	17,665	5,004
Passaic Water Co............	9,710,000	142,022	17,864	15,220
Perth Amboy Water Dept.....	9,672,000	50,604	7,009	5,804
Aquacknock Water Co........	7,000,000	90,294	9,767	8,073
Plainfield Union Water Co....	6,850,000	59,000	13,930	7,162
New Brunswick Water Dept.	6,760,000	37,645	7,148	2,522
Middlesex Water Co.........	3,448,000	27,800	3,946	3,574
East Orange Water Dept......	3,256,000	50,710	8,370	8,370
Rahway Water Dept..........	3,113,000	11,042	2,389	156
Commonwealth Water Co....	3,055,000	61,482	10,562	10,482
Montclair Water Co..........	2,790,000	51,868	6,684	6,684
Orange Water Dept..........	2,480,000	33,268	4,874	4,874
Bound Brook Water Co......	881,000	7,208	1,064	240
Bergen Aqueduct Co.........	810,000	12,570	2,537	171
Watchung Water Co.........	790,000	5,500	1,157	40
Garfield Water Dept..........	743,000	19,381	2,700	2,680
South Orange Water Dept....	638,000	7,500	1,700	1,604
Hawthorne Water Dept.......	493,000	5,135	......	......
Essex Fells Water Dept......	319,000	9,324	1,546	1,546
Wallington Water Dept......	236,000	5,715	666	222
Haledon Water Dept..........	150,000	4,322	474	321
South River Water Dept......	141,000	6,596	1,357	1,065
Short Hills Water Co.........	104,000	2,200	429	356
Ramsey Water Dept..........	100,000	3,250	331	331
Milltown Water Dept........	77,000	2,573	......	......
Piscataway Water Co........	20,000	450	134	3
Yantacaw Water Co..........	18,000	500	114	5
New Orange Park W. H. & L. Co.	12,000	140	28	......
Lodi Water Dept............	......	8,175	1,077	718
Totals	244,236,000	2,070,482	283,777	205,361

TABLE No. 1—*Continued*

PRESENT WATER SUPPLIES CLASSIFIED BY SOURCES

		Output in 1920, million gallons per day	
Surface Water			
Passaic River and Tributaries:			
Pequannock	47.7		
Rockaway	53.5		
Little Falls Plant	50.5	151.7	
Hackensack River at New Milford		29.4	
Rahway and Elizabeth Rivers			
Elizabethtown Water Company	8.41		
Rahway Water Department	3.11	11.52	
New Brunswick Water Department		6.76	
Orange Water Department		2.48	
Middlesex Water Company		1.28	
Bound Brook Water Company		0.86	
Total			204.
Ground Water			
Elizabethtown Water Company		10.56	
Perth Amboy Water Department		9.67	
Plainfield Union Water Company		6.85	
East Orange Water Department		3.26	
Commonwealth Water Company		3.05	
Middlesex Water Company		2.17	
15 Small Systems		4.44	
			40
			244.

CLASSIFIED BETWEEN PUBLIC AND PRIVATE OWNERSHIP

	Publicly Owned Plants	Privately Owned Plants
Population supplied	983,335	1,087,147
Output in Gallons per Day	136,690,000	107,546,000
Gallons per capita	139	99
Number of Services	130,271	153,506
Number of Meters	86,573	118,788
Percentage of Services Metered	66	77

CLASSIFIED WITH REFERENCE TO COMPLETENESS OF METERING, BY DIVIDING INTO TWO CLASSES, ABOUT EQUAL IN SIZE

	Group 1 12 Systems 90% metered and over	Group 2 21 Systems less than 90% metered
Population supplied	1,139,753	930,729
Output in Gallons per Day	100,929,000	143,307,000
Gallons per capita	89	154
Number of Services	146,738	137,039
Number of Meters	138,391	66,970
Percentage of Services Metered	94	49

(2) Jersey City uses the Rockaway River, another tributary of the Passaic, with an area of 119 square miles. The Boonton Reservoir gives partial development, but it is not large enough to make available the full capacity of the source. More storage would increase the yield and there is understood to be an opportunity for the needed amount, but no plans have been made. As the works stand they will supply 57 mgd. The population on this catchment area is large and increasing. Sanitary supervision, supplemented by chlorine treatment is now depended on to maintain the quality of the water; but a trunk sewer to remove the greater part of the polluting material is proposed.

(3) The East Jersey Water Company draws from the Passaic River at Little Falls. There is no storage, and the natural flow of the river is depended on. It has been sufficient up to the present time, but drawing heavily on it reduces the flow of the river. There are large industrial uses from the river below the intake, and diversion must not be carried too far, or they will suffer. The water is filtered before delivery. The plant as it stands is able to meet a draft of 50 mgd. and this average was maintained in 1920. This plant can be easily increased in size; the important matter is that too much water should not be taken from the river.

In addition to the above, the following prospective developements of tributaries of the Passaic River may be mentioned.

(4) The North Jersey District Water Supply Commission has begun to develop a supply from the Wanaque River and proposes to obtain from it a supply of 50 mgd. This is not yet in service and the time of its completion is not known to us.

Greenwood Lake at the headwaters of the Wanaque is a feeder of the Morris Canal. It has ample storage for its whole catchment area, and as a source of water supply, if it were available for such use, would yield 25 mgd.

(5) The Hackensack River has a catchment area of 115 square miles. Reservoirs now under construction will bring the storage to 4 billion gallons and the maintainable output to 41 mgd. The water is filtered before delivery. It would be possible to develop a further quantity of water up to 65 or even 70 mgd. by the construction of much larger reservoirs (partly in the State of New York) but there may be some doubt as to whether it will be wise to do this. The following matters must be considered. The population per square mile upon the Hackensack catchment area, (Table 3, Page 21), is greater and is growing more rapidly than upon other areas under consideration. The catchment area is flat and the res-

ervoir sites on it are less advantageous than those in higher and more hilly country. A large part of the catchment area is in the State of New York and is beyond the jurisdiction of New Jersey. The part of the catchment area in New Jersey is within the area of the District as defined above and suburban communities are developing rapidly upon it.

(6) Minor surface supplies furnish 23 mgd. Some of these are permanent in character, but others are obtained from populous areas that must be abandoned sooner or later because of the quality of the water. Water so abandoned for public supply may be continued in use for industrial purposes if a local market for it can be found.

One important addition may be expected to the supplies under this heading, namely, a supply from the Raritan River on which much construction work has already been done, and which is authorized to use 20 mgd., from that source. It is now assumed that this will be carried through, and that this 20 mgd. will be available to replace inferior surface waters now in use.

(7) Ground Water Supplies. There has been a great increase in the amount of ground water used for public water supplies in the district in recent years, and also, it may be added, in that obtained from wells at various industrial plants. Generally the water obtained in this way is of good sanitary quality, although frequently hard. In general the wells may be expected to go on delivering water of good quality for a long period of years. Some of them may fail to keep up their present rate of output in dry years, while others and additional wells may be developed to produce more water. It is now assumed that the present rate of output in the aggregate will be maintained, but no considerable increase is expected.

Capacity of Present Sources

The capacities in a dry year of present sources may be thus summarized.

		MGD.
1.	Pequannock—Newark	57
2.	Rockaway—Jersey City	57
3.	East Jersey—Little Falls Plant	50
4.	Wanaque (50 mgd.) not yet available	..
5.	Hackensack	41
6.	Minor Surface Supplies	23
7.	Ground Water Supplies	40
	Total Available Supply	268
	Consumption in 1920	244

3. Population and Water Requirements

It is possible to forecast population and water requirements for ten or twenty years with comparative accuracy by assuming that past rates of growth will be continued. The results so reached, while not precise, are close enough for practical purposes. But for a fifty year period the errors that may result from following this simple procedure may be greater. Growth in population and water requirements depend on many things that are not known and cannot be determined long in advance.

Past Population Growth

The Metropolitan District, including both the six counties in New Jersey, with an area of 1018 square miles, and the area occupied by the present city of New York, and by Westchester and Nassau Counties, with a combined area of 1021 square miles, has increased in population steadily during the 130 years covered by the U. S. Census records. The average rate of growth has been slightly over 3% per annum, and the regularity has been remarkable. For the first 50 years of this period the greater growth was on the New York side of the river. Beginning with 1840 the New Jersey communities began to grow more rapidly; and since that time their percentage growth has equalled or exceeded that of the New York communities. From 1840 to 1870 the growth in New Jersey was particularly rapid. From 1870 to 1910 it fell off slightly and from 1910 to 1920 still more. These are shown graphically in Figure 2 (page 15).

Future Population Growth

There is no doubt that the rate of increase must be some time limited. It is not conceiveable that the average rate of 3% per annum of the last century will be permanently maintained. If it were the population in the whole district, including both New York and New Jersey, would be expected to reach sixteen millions in 1943; thirty-two millions in 1966; sixty-four millions in 1989; and one hundred and twenty-eight millions in 2012. This leads to an absurdity.

There has been a reduction in the rate of growth in the last decade. We do not know whether this marks the beginning in the

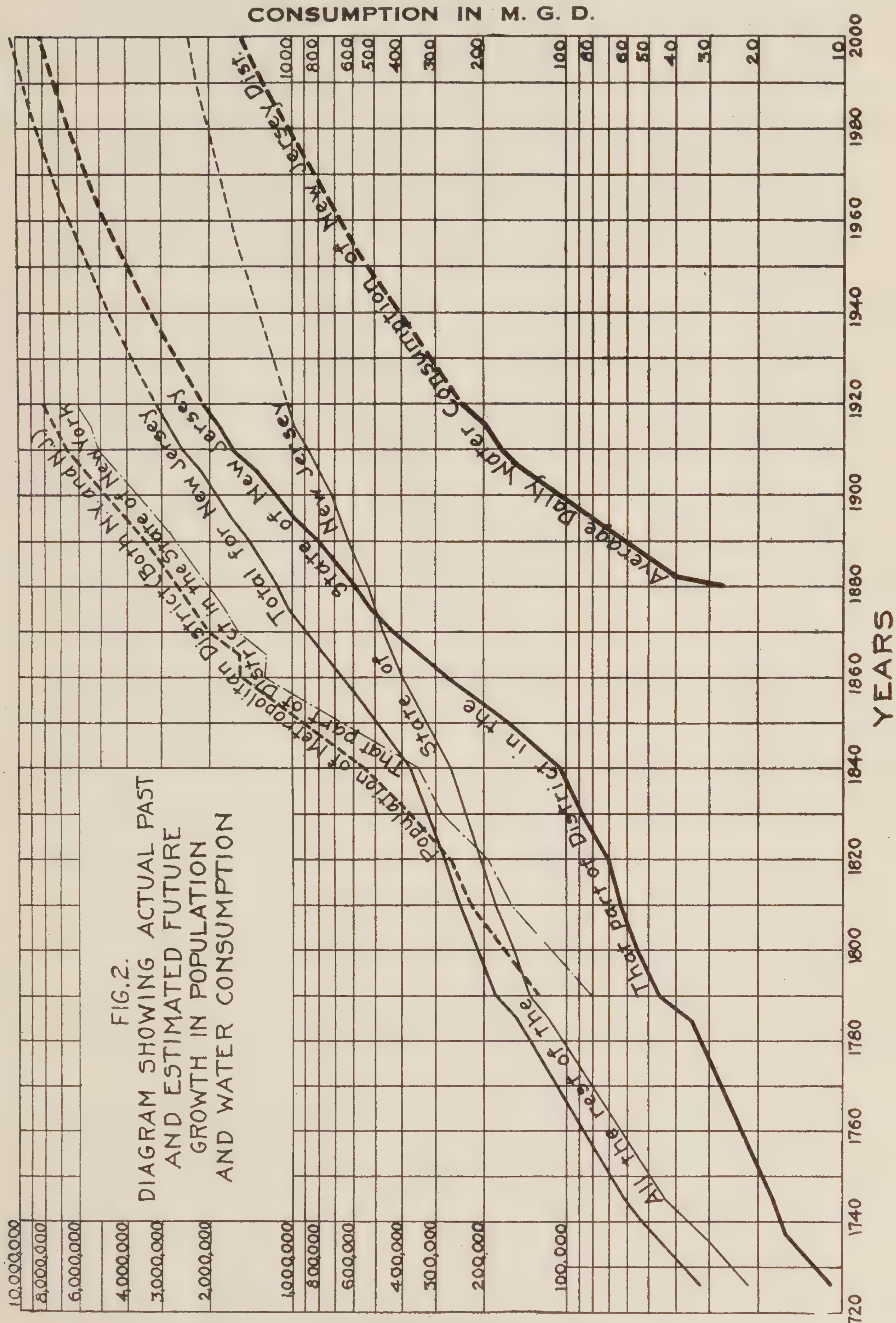

FIG. 2.
DIAGRAM SHOWING ACTUAL PAST AND ESTIMATED FUTURE GROWTH IN POPULATION AND WATER CONSUMPTION

permanent reduction which must be some time expected, or is simply a slowing down due to war conditions, to be followed by another period of still more rapid growth like that which followed the Civil War. Time only will answer this question.

In thinking of the probable growth in the next fifty years it has been considered that the population of the whole country might almost double; but the growth will be relatively greater in the south and west, in regions remote from New York and less directly tributary to it than in those parts that have grown most in the last century.

It may also be considered that other and newer centers are competing for the manufacturing now carried out in New York and in New Jersey, and that many of these new centers have advantages in being nearer to sources of raw materials and to markets.

A schedule for our guidance has been prepared in which it is assumed that 10.6% of the entire growth of the country in the next fifty years will be in the New York Metropolitan District, and that of this thirty-five per cent. will be in New Jersey.

TABLE No. 2

ACTUAL PAST AND ESTIMATED FUTURE POPULATIONS IN THOUSANDS

Year	Six counties in N. J.	All the rest of N. J.	Total for N. J.	Seven counties in N. Y.	Total Metropolitan District	U. S.
1790	46	138	184	82	128	3,928
1800	55	156	211	115	170	5,308
1810	63	183	246	160	223	7,236
1820	71	207	278	195	266	9,639
1830	88	233	321	289	377	12,860
1840	106	267	373	450	556	17,064
1850	162	328	490	764	926	23,191
1860	275	397	672	1,275	1,550	31,439
1870	436	470	906	1,600	2,037	38,545
1880	591	590	1,131	2,044	2,636	62,947
1890	818	627	1,445	2,680	3,498	62,947
1900	1,158	726	1,884	3,677	4,835	75,995
1910	1,659	878	2,537	5,134	6,793	91,974
1920	2,114	1,042	3,156	6,090	8,204	105,711
1930	2,650	1,190	3,840	7,270	9,920	122,000
1940	3,300	1,340	4,640	8,510	11,810	139,000
1950	4,000	1,510	5,510	9,830	13,830	158,000
1960	4,800	1,680	6,480	11,230	16,030	178,000
1970	5,600	1,860	7,460	12,690	18,290	200,000

The annual percentage growths in the Metropolitan District and in the whole United States are as follows:—

ANNUAL PERCENTAGE GROWTH

Period		Number of years	In New Jersey	In New York	For the Whole District	The Whole United States
1726 - 1790	actual	64	2.28	....	....	....
1790 - 1840	"	50	1.67	3.47	2.98	2.98
1840 - 1870	"	30	4.84	4.32	4.42	2.76
1870 - 1910	"	40	3.40	2.95	3.05	2.20
1910 - 1920	"	10	2.45	1.70	1.92	1.40
1920 - 1970	estimated	50	1.95	1.49	1.62	1.28

Whether the conditions that are assumed for fifty years hence are actually reached in 1970, according to the schedule now presented, or in a shorter period, as would be the case if recent rates of growth were continued, or in a longer period, makes but little difference with the consideration of the ultimate problem of water supply. The ultimate requirements rather than the times at which they are to be expected are important.

Uses of Water for Industrial Purposes

The primary use of water is for domestic purposes, but a considerable quantity is suplied for industrial purposes. The use of water from public systems for industrial purposes has increased more rapidly than the business as a whole. In addition to the water supplied from public systems, the industries use a large amount of water from other sources which they themselves control. These are mainly wells at the various works.

Complete data are not available, but some information and estimates for systems covering a great part of the District have been secured. From these it is estimated roughly that 32% of the total water output of public systems is used in industrial operations. This includes water supplied to railroads and to steamship companies.

Water wasted by leakage from pipes and from leaky plumbing fixtures in unmetered houses may be estimated at 30%.

This amount is based on experience in American Water Works systems that have been studied in detail, and not upon data available from the systems in this district. It represents our best judgment of the probable amount for these systems.

Water actually used for public and domestic purposes, making up the remainder, is 38% of the total output.

The total amount of water used for industrial purposes from both public systems and private sources at the present time is considerably more than domestic requirements.

PRESENT AND ESTIMATED FUTURE CONSUMPTIONS

Gallons Per Capita Daily

Year	Public and Domestic requirements	Industrial requirements from public supplies	Preventable waste	Inevitable waste	Total required from public supplies	Private industrial supplies	Total water requirements
1920	45	38	18	17	118	19	137
1930	49	42	9	18	118	17	135
1940	53	46	5	19	123	15	138
1950	57	50	3	20	130	14	144
1960	61	55	1	21	138	12	150
1970	65	60	0	22	147	11	158

Year	Population	Million Gallons Daily: Total required from public supplies	Private industrial supplies	Total Water requirement
1920	2,114,000	244	40	284
1930	2,650,000	315	45	360
1940	3,300,000	407	50	457
1950	4,000,000	520	55	575
1960	4,800,000	660	60	720
1970	5,600,000	820	60	880

ANNUAL PERCENTAGE GROWTH IN WATER OUTPUT

Year	From Public Supplies	Total Water Requirements	
1890 - 1905	5.86	....	Actual
1905 - 1920	3.75	....	"
1920 - 1930	2.60	2.40	Estimate
1930 - 1940	2.60	2.40	"
1940 - 1950	2.42	2.30	"
1950 - 1960	2.34	2.28	"
1960 - 1970	2.17	2.08	"

Past Water Growth

The growth of the water supply business in the last 50 years has been rapid. In 1870 it was just beginning; in 1880 the combined output of the few systems in the present District, summed up from data contained in the report of the Tenth Census, was 26 mgd. In 1882 it was estimated by Mr. Vermeule at 40 mgd. In 1890 it had increased to 60 mgd., as determined from data found in the Amer-

ican Water Works Manual. In 1905 it had increased to 141 mgd. and in 1920 to 244 mgd. In the last 15 years the average annual increase has been about 7 mgd.

The use of water has increased more rapidly than the population. Domestic per capita use has increased because people live in larger houses with more fixtures, and also because water is so cheap, that, within limits, waste does not increase water bills to the point of demanding attention. The industrial use of water has increased because of the unequalled growth in manufacturing, and because private supplies do not increase with the growth of business, and new requirements, whatever they may be, must be met by the public systems.

Future Water Growth

This increase in per capita use of water, which has been going on since water works were first built must be expected to continue for a time at least. On the other hand, part of the present waste can be stopped and this must be done, and, when accomplished, there will be a certain temporary reduction in per capita requirements.

In Figure 2, (page 15), are shown the actual past and estimated future populations, since the first Census of 1728, and the water consumptions since 1880.

It is not at all certain that the rates of growth shown by these tables will be realized; but it does not seem prudent to use lower ones. All that we can hope to do is to lay out a program sufficiently large so that it will not prove inadequate, and, on the other hand, to arrange so that it can be carried out in steps, each within the reasonable financial ability of the community at the time.

It would be disastrous to embark upon a program that was too ambitious and that brought too heavy a burden on the present generation; and equally so to fail to make due provision for conditions that may be anticipated at some remote time.

Fortunately water works systems can be built progressively as needed; and it will never be necessary to incur obligations so far in advance of the needs of the time that they would be embarrassing if further growth proved to be less rapid than expected.

4. Water Resources of the State

A canvass has been made of areas that might be used for future water supply. The abundant literature and reports upon the subject have been consulted. The unequalled state maps were used as a basis for all studies. Areas that seemed promising were visited, and sites for works examined. There were no surveys and no borings. Dr. Kummel has advised in regard to underground conditions, and we have visited together all of the more important sites.

It may be appropriate to add a word about the State Maps. The New Jersey maps in their several editions showing topography, geology and forests, and the large scale maps covering a part of the area, give such a basis for study as is rarely available.

If it had not been for these maps it would have been necessary to have made topographical surveys of the areas under consideration; our studies would have required years instead of months, and the cost of the field work, to arrive at anything like the point actually reached might easily have exceeded the $60,000 reported as the original cost of the state survey.

All the studies have been strictly preliminary in character. It has been our endeavor to get an accurate general view of the entire field without stopping for unnecessary details; and to block the matter out in broad general terms, sufficient to demonstrate the feasibility of each source, and to permit an approximate estimate of the amount of water that could be realized from it.

Consideration has been given to the probable cost of building the necessary works; but this has gone only far enough to serve as a general guide to the relative possibilities of the several sources.

Catchment Areas Considered

Plate No. 1 shows in red on the map of the state the general location of each of the areas that have been considered. Table No. 3 (page 21), shows some important data in regard to them.

The populations per square mile shown in Table No. 3 must be taken as only rough approximations, especially for the smaller areas. The Census returns follow township and municipal boundaries. The catchment areas of water sources follow other lines. In making this table the population for each township or municipality has been distributed somewhat arbitrarily among the different catchment areas upon which it is located, this being the only feasible procedure.

TABLE NO. 3 - POPULATION and ANNUAL WATER CROPS on CATCHMENT AREAS.

CATCHMENT AREA	POPULATION				AREA SQ. MILES	WATER SURFACE WHEN DEVELOPED		AVER. ELEV. OF ENTIRE AREA	BASE RUNOFF (IN.) TO WHICH CORRECTIONS ARE APPLIED	ESTIMATED MEAN RUNOFF		
	TOTAL	PER SQ. MILE										
	1920	1900	1910	1920		SQ. MILES	%			INCHES PER ANNUM	M.G. PER ANNUM	M.G.D.
Flat Brook	889	19	16	14	62.8	4.0	6.4	907	19.5	24.2	26410	72.3
Paulinskill	7978	70	72	64	124.5	6.5	5.2	696	19.9	23.6	51060	139.8
Beaver Brook	1051	37	40	33	31.5	4.8	15.3	583	19.7	21.0	11500	31.5
Pequest	5486	50	58	48	115.6	2.5	2.2	671	20.1	24.0	48220	132.0
Pohatcong	370	54	50	46	8.0	0.1	1.2	823	20.1	25.2	3500	9.6
Musconetcong	10045	74	86	82	122.5	7.8	6.4	846	20.5	24.8	52800	144.6
Spruce Run	345	80	77	40	8.7	0.3	3.4	809	20.4	25.0	3780	10.3
South Branch	2883	57	53	52	55.3	1.4	2.5	869	20.7	25.8	24790	67.9
Black River	1925	55	56	62	30.9	2.3	7.4	801	20.9	24.7	13260	36.3
Peapack Brooks	592	119	106	100	5.9	0.1	1.7	626	21.0	24.7	2530	6.9
North Branch	2287	86	102	94	24.4	0.6	2.5	668	21.1	25.0	10600	29.0
Millington	5693	89	105	102	55.4	24.5	44.3	350	21.7	16.8	16170	44.3
Sum: Long Hill System	39544	61	67	61	645.5	54.9	8.5	728		23.6	264620	724.5
Rockaway	24966	190	179	210	119.0	3.1	2.6	806	21.1	25.8	53360	146.1
Pequannock	1024	18	17	16	63.7	3.1	4.9	1043	21.2	27.0	29880	81.8
Greenwood Lake	554	23	22	20	27.1	3.0	11.1	905	21.1	24.9	11730	32.1
Wanaque	1678	16	20	25	67.3	3.0	4.5	701	21.3	25.0	29240	80.1
Ramapo	14966	79	102	102	146.6	2.1	1.4	712	21.6	26.0	66240	181.4
Millington	5693	89	105	102	55.4	0	0	350	21.7	23.9	23010	63.0
Balance Passaic to Little Falls	67482	160	198	239	282.1	0	0	356	21.8	24.1	118150	323.5
Little Falls to Great Falls					24.0	0.3	0.1	356	21.8	24.1	10050	27.5
Sum to Little Falls	116303	114	133	153	761.2	14.3	1.9	603		25.1	331610	908.0
" " Great Falls					785.2	14.6	1.9	603		25.0	341660	935.5
Balance Passaic to Little Falls (after both res.)					282.1	61.5	21.8	356	21.8	20.6	100990	276.5
Total Passaic to Great Falls (" " ")					785.2	76.1	9.7	603		23.8	324500	888.5
Passaic to Little Falls (without Millington)	110610	116	135	156	705.8	14.3	2.0	623		25.2	308600	845.0
Passaic to Great Falls (without Millington)					729.8	14.6	2.0	623		25.1	318650	872.5
Passaic " " " (" " & with res.)					729.8	76.1	10.4	623		23.8	301490	825.5
Raritan, total	32072	68	69	68	468.1	53.2	11.4	462		22.1	180100	493.0
Raritan, excluding Long Hill System	24040	69	69	70	342.9	48.5	14.1	336	21.0	21.0	125140	342.6
Hackensack	37348	156	260	325	115.0	2.0	1.7	197	22.4	23.5	46970	128.6
Mullica	10883	34	37	46	239.0	0	0	75				
Wading River	1169	7	7	7	173.0	0	0	94				
Sum	12052	23	25	29	412.0	53.8	13.1	83	19.5	18.3	131030	358.7

The runoff data entered for convenience in Table No. 3 will be considered in part seven, to which reference is made for a further description of the table.

Proposed Reservoirs

To develop these catchment areas for public water supply a number of reservoir sites have been selected. Table No. 4 shows some of the more important data for them. All these rest upon state maps, and state maps only, and not upon actual surveys.

TABLE No. 4

DAMS AND RESERVOIRS

Name	Length of main dam at flow line Feet	Depth of Water in Feet Max.	Depth of Water in Feet Ave.	Area of water surface, square miles	Elevation Flow line	Elevation Low water	Capacity in Billion Gallons To bottom	Capacity in Billion Gallons Available
Flat Brook	1,160	120	49	3.90	480	445	40	24
Paulinskill	600	105	23	3.80	460	433	18	13
Beaver Brook ..	1,430	85	26	4.70	440	413	26	18
Pequest	1,100	60	28	1.70	435	405	10	8
Musconetcong ..	1,400	70	22	2.90	420	390	13	10
So. Br. Raritan.	610	30	9	0.60	505	475	1	1
No. Br. Raritan.	1,500	100	38	0.52	335	310	4	2
Long Hill Res...	850	105	64	24.50	320	280	328	182
Passaic at Little Falls ...	7,700	42	22	61.50	200	180	290	220
Raritan	12,360	90	29	48.50	140	120	295	157
Mullica & Wading Rivers	33,400	30	12	53.80	40	25	140	106

Upland Catchment Areas

The water resources of New Jersey are great and favorably situated. The state must have been made for such Metropolitan development as is now taking place, and as may be expected in the next century. There is a concentration of population needing water; and close at hand is a region that could hardly be improved as a place from which to draw water.

Within 50 miles of the urban center are found catchment areas with a combined area of 1,718 square miles, that can be made tributary to future water works. This area is abundantly provided with excellent sites for reservoirs, and no area has been included that could not be readily and economically developed. Of this area 141 square miles of the Passaic catchment area are in the state of New York and the remaining 1,577 square miles are in New Jersey and

amount to 21% of the total area of the state. The southern streams are not included in this statement.

Better reservoir sites are not to be found anywhere. All of the surplus water from the whole area can be held until it is needed, and made available for use. The rainfall is twice that required for agriculture. Its abundance provides a large surplus that makes it easy to develop public water supplies.

Water is now drawn from some parts of this area, but the storage so far provided is only enough to develop a fraction of the quantity available. The Passaic River and its tributaries furnish the greater part of the present supply; but a complete development of the Passaic River alone would produce four times the quantity of water now used from it.

Other parts of this upland area, equally available, although at a greater distance, do not contribute to the water supply of the District. The works to develop them will be more costly but not difficult. All of this area may possibly be some time needed, not within the assumed fifty-year period, but long afterward.

Population Upon Catchment Areas

Public water supplies are best drawn from catchment areas that do not have much population upon them. The ideal is uninhabited forested mountain land. Population means pollution. The effects of pollution may be removed by long storage in large reservoirs or by filtration and other treatments; but sparsely populated areas are wisely sought and preferred.

The 1,718 square miles of potential catchment area in New Jersey are well situated in this respect. The area is near to the populous district and also, in a general way, it is between New York and Philadelphia, two very large cities, and yet it is inhabited for the most part by only a scattered rural population.

There are only a few important industries, and most of the reservoir sites that would need to be flooded in a complete development of the water do not contain considerable villages or large mills. In this respect conditions are unusually favorable. In other states it has been necessary to flood and destroy villages and towns, and many industries, that cities might have water.

Complete Development of Upland Sources

If there were present need for it, there is no reason why the available water supply from the whole of these 1,718 square miles of

catchment area could not be developed. To do this the land to be actually flooded by the various reservoirs, and suitable marginal strips about each, and the additional areas required for aqueducts and other structures, and some areas required as protection for the quality of the water would need to be bought. The houses and populations upon those parts of it to be covered with water would be removed.

With complete development of this entire area 1,550 mgd. of water could be produced. This is more than six times the present rate of output and only a little less than twice the amount estimated as required in 1970.

It will not be necessary to use the whole of this area for water supply purposes in a fifty-year term. Perhaps all of it will never be needed. This we do not and cannot know. Whatever is thought as to the ultimate requirement, decision should be made as to which parts of the area are to be reserved and attention concentrated on them. It would be desirable to secure control of all areas likely to be needed, even in a remote future, but to what extent and under what conditions remains to be determined.

Reserving Sites for Future Use

The difficult problem relates to the future. While the population of the six counties is increasing from two millions to five and perhaps ultimately to ten millions and more, conditions on the upland catchment areas needed to supply this greater population with water cannot be expected to remain unchanged. If there was nothing else, the construction of good roads, making the back country easily accessible by automobile, in connection with increasing wealth and ability to make use of remote but attractive areas for residence and recreation, would give cause for serious concern.

Newark has secured a large part of the Pequannock catchment area from which her water is drawn, and has largely depopulated it. This course has advantages; but it is not thought to be necessary or even desirable to buy and depopulate any large part of the 1,718 square miles of prospective catchment area, or of such parts of it as may be selected. It would be desirable to control the part that is selected to the extent of preventing new industries from being established on it, and new centers of population. New summer resorts would be undesirable. There are other areas in the state well adapted to such purposes, and if some way could be found to divert such development in other directions it would be most helpful. Some

such method as is now used in zoning in cities may be found applicable, with modifications, to rural areas.

Purchase of Land for Water Control

If no better way can be found to control the future of the areas that are selected, resort must be made to purchase. Not purchase of the entire area, but of such areas as can be bought from time to time, with the deliberate purpose of removing from the market as much as possible of the land that might otherwise be used by those who would develop it in a way that would be undesirable.

And with such a policy of purchase might well be coupled a policy of making long term leases to present owners. That is to say, whenever a piece of land was bought it would be leased to the former owner for life, if he wished, or to someone else if the owner did not care for it, for use for agricultural purposes, under reasonable restrictions. Following this policy would reduce to a minimum the disturbance and hardship to present owners, and on the other hand would make certain future control of the necessary areas. All land for which there is no better use would be devoted to forestry.

Morris Canal

The Morris Canal Company controls a number of catchment areas and storage reservoirs used to furnish water to its canal. These reservoirs are capable of being used for water supply purposes. From a water supply standpoint, the most important of these are Lake Hopatcong and Greenwood Lake. Cranberry Pond, Green Pond and others are smaller. The Canal Company owns the fee of the flooded lands and of the outlets. With some small exceptions it has the right to use all the water from these sources that it requires for the purposes of navigation. As the navigation is limited, the amounts required are not large.

It would be possible to use Lake Hopatcong and Greenwood Lake as storage reservoirs for water supply if navigation were abandoned, and if the necessary rights were acquired for public water supply. This has not been assumed in any of our studies.

It is assumed that the water from these lakes, as far as not required for navigation will flow down natural channels; and storage for it has been found on other sites sufficient to utilize it all. Carrying out any or all of the projects mentioned in this report would not interfere in any way with the present régime of Lake Hopatcong and Green-

wood Lake. It may be that additional sanitary measures to protect the quality of the water would be desirable, but if so, these measures would not go beyond those that might be wisely adopted to protect the health of the people who themselves have cottages upon the lakes.

The lakes if used for storage purposes would have some value for water supply purposes, and would replace an equivalent amount of storage that it would otherwise be necessary to build; but, as stated, this has not been taken into account in any way in the projects now considered.

The projects for developing water supplies that have been considered do not require the abandonment of the Morris Canal nor would they interfere with its water supply. In one case a reservoir has been considered that would flood a portion of the canal, but arrangements could no doubt be made for conducting the canal business through the reservoir.

Deductions from the quantities of water available have been made in all cases for water required for navigation, and the estimates presented are therefore net.

If the canal should be abandoned for navigation and its water rights acquired in the interest of public water supply, these deductions would no longer be necessary and something would be added to the estimates. The matter is not large enough to be of first importance in the broad consideration of the future water supply of Northern New Jersey.

There is one thought that may be recorded. The canal seems to have the right to use the water that it controls for purposes of navigation only. If it were abandoned for navigation, and nothing else done, apparently the several rights to water would revert to the original owners. If the canal were to be abandoned it is therefore suggested that it might be well to take the necessary procedure to condemn for public use all the water rights used for navigation that would be useful for public water supply, and to do this before, or at the same time as the abandonment of the canal. In other words, it might be easier and cheaper to acquire these rights before the restrictions upon them are removed and before they have actually reverted to the original riparian owners and their successors.

Hardness

Generally speaking all of the proposed New Jersey supplies will be soft. Dr. R. B. Fitz-Randolph, Assistant Director of the State Department of Health, has placed at our disposal a summary of analyses

made by his department. This study has not extended to making analyses of waters from the proposed sources. Hardness of a supply developed by storage reservoirs cannot be accurately predicted from analyses of water flowing in streams before storage. This is because the reservoirs are mainly filled with the soft winter and spring flood waters while analyses represent in greater measure the moderate flows of other parts of the year.

In the feeders of the Long Hill system there are limestone formations interspersed with the other rocks; and these will have the effect of adding something to the hardness of the water. However, the percentage of limestone is small; and from general experience with water supplies, and from an examination of the records that Dr. Fitz-Randolph has placed at our disposal, it is clear that the water obtained will be comparatively soft. The Wallkill water is hardest and this we do not propose to use.

The Raritan would probably be as hard as the Long Hill water. The Mullica and Wading River water would be exceedingly soft, as is also the water from the Passaic and its tributaries.

As to Those Whose Property Will be Taken

Some of those who read this report will find that their homes are in the areas that are affected or that the water that they use for power or other purposes will be taken in whole or in part by the proposed developments; and some such readers will perhaps be inclined to raise all obstacles to any project that would affect their property.

Such readers should remember, in the first place, that only a part of the projects mentioned can, in any event, be carried out in the near future; and only those living in the area covered by the one selected for first development will be affected at this time. The Constitution of the United States provides that private property shall not be taken for public use without due process of law and just compensation, and these requirements will certainly be complied with.

It is to be hoped that those who represent the public in carrying out any plan for additional water supply will not only administer justice, but will be considerate of the interests and feelings of those who are asked to give up something for the general good, and to make it as easy as possible for everyone who is disturbed.

Water Supply of the Rest of the State

This investigation relates mainly to the future water supply of the Metropolitan District within the six counties. The sources that

have been considered for it, as far as known, can be taken without limiting in any way future water supplies of the remaining cities in the State. The resources of all other parts of the state are sufficient to take care of their requirements.

The probable need of greater supplies along the beaches in the southern part of the state at some future time will be mentioned briefly. It would also be proper to add to any legislation that any cities near areas taken and that would naturally and economically secure water from such areas should be furnished with the water that they need, under equitable arrangements by which they would pay a proportionate part of the cost of securing, storing and making available the water supplied to them. This does not apply to water used for power; only for water for public water supplies and other primary uses. In other words, the whole project can and should be carried out so as not to affect adversely the water supply situation of any community in the State.

5. The Four Principal Developments Considered

Four principal developments of water for the district have been considered. They may be mentioned in order, beginning with the ones nearest at hand.

1. Complete (or partial) development of the Passaic River.
2. Long Hill Reservoir fed by northern streams.
3. Raritan development, supplemented ultimately if needed, by water from the Delaware River.
4. Mullica and Wading Rivers, and other Southern streams.

We will now present a brief description of these four main possible sources, describing what would be involved in the development of each.

Passaic Great Reservoir

The Passaic River has been, and is, the principal source of water supply in the District. There is an opportunity to build a dam a short distance above Little Falls to form a great reservoir to store water for the complete development of this source. Full development would be reached by the construction of a reservoir with a flowline at elevation 200, forming a lake extending 18 miles from Chatham to Pompton, with deep bays to the westward in the valley of the Rockaway River extending almost to the Boonton Dam, and in the valley of the Whippany River extending almost to Madison. The reservoir would cover 61 square miles or 15 times the area of Lake Hopatcong. Figure No. 3 (page 30), shows the position and extent of this reservoir.

A lower flow line would not do, because, with fluctuating water levels, necessary to utilize the water, too much flat bottom would be exposed.

Such a dam might have been built years ago without serious damage to any one. By its use the varying flows of floods and dry periods would be equalized to a continuous maintainable flow of 757 mgd. If 80 mgd., an approximation to the natural minimum flow of the stream, were permitted to flow down the river for industrial purposes and to keep the lower channel of the river sweet, there would remain 677 mgd. available for public water supply.

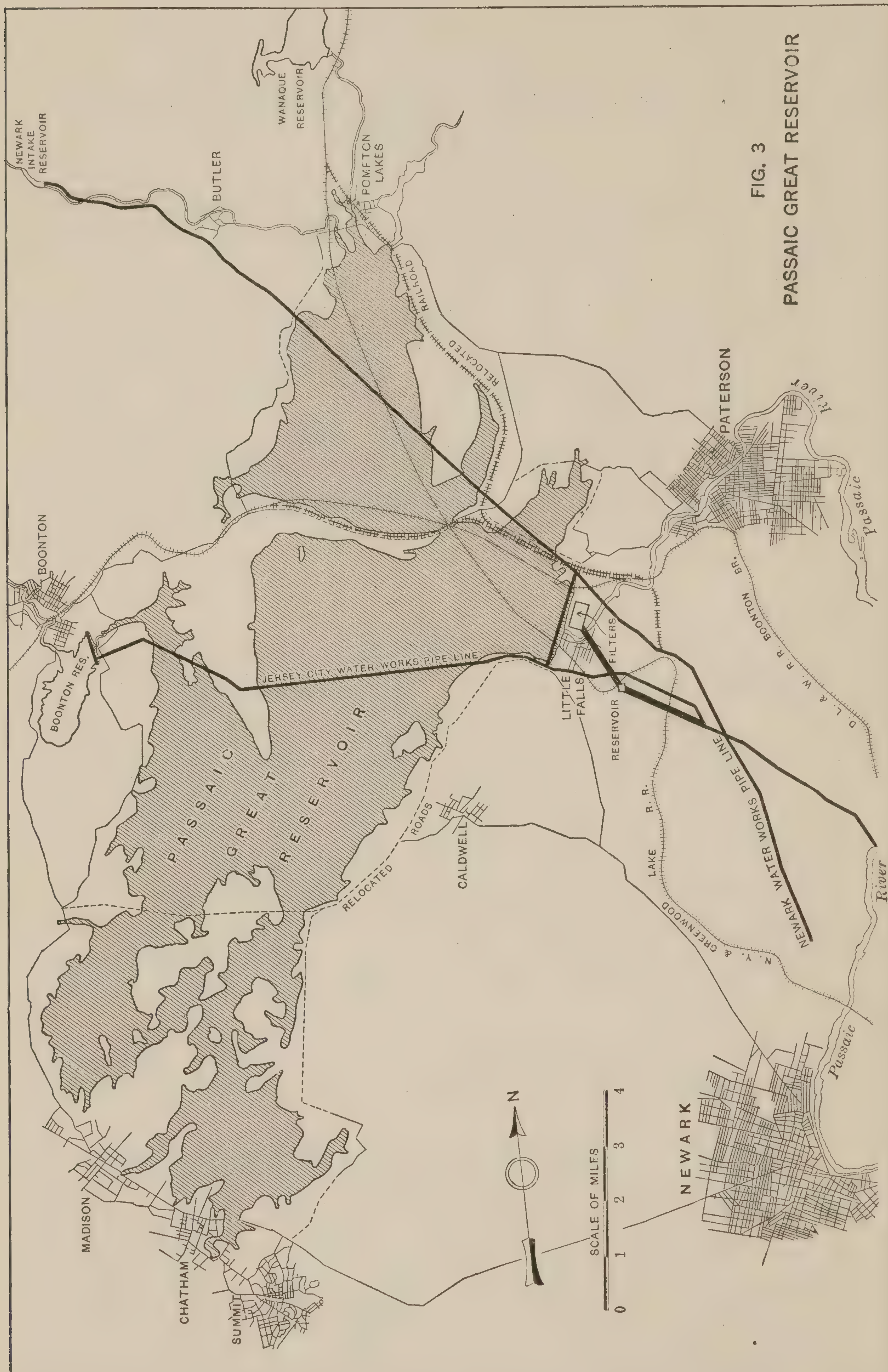

FIG. 3
PASSAIC GREAT RESERVOIR

In 1920, 152 million gallons daily of Passaic water were delivered in the district. In addition, 6 mgd. of ground water were taken from it. Complete development would permit a total 677 mgd., or an addition of 519 mgd. without reducing the flow of the river below 80 million gallons daily at Great Falls.

It will be more difficult to carry out this development at the present time, because of the great increase in the last years in the use and value of the lands to be flooded. State roads have been built across the valleys. Industrial establishments and houses have sprung up; and it will cost a great deal of money to buy all the land necessary for building the reservoirs, and to pay the damages that will result.

It may be of interest to enumerate some of the structures that would be flooded. In the first place there are about 2,150 dwellings of all kinds. Three hundred and fifty of them are farm houses, 850 are small suburban cottages, and 375 are larger and better houses. Then there are 600 summer cottages, many of them merely shacks along the river. About 16% of the houses and nearly all of the shacks are below the flood level, and would be inundated by a flood like that of 1903. There are 8 churches. Among them are two beautiful old stone churches. The old stone churches would have to be rebuilt carefully to the original plans on sites above the flow line. Five cemeteries would also be moved. There are eleven schoolhouses, ranging from small country schools to large modern school buildings. There are four water works plants including the pumping stations on Canoe Brook of the Commonwealth Water Company and of East Orange which would be below the flowline and would have to be replaced with equivalent facilities. There are also a steam power plant and a sewage pumping station and two sewage disposal works in the flooded area. The water-power at Pompton Lakes would be submerged. The DuPont Powder Works at Wayne, a number of small mills, several dairies, chicken farms, kennels, etc., are below the flow-line.

All these probably represent the equivalent of the buildings and industries to be found in an average city of ten or twelve thousand inhabitants.

The Delaware, Lackawanna and Western Railroad crosses this reservoir. It would be necessary to change its location slightly and to carry it across the deepest part of the reservoir on solid fill near Mountain View.

Many important highways cross the reservoir. The whole road system would have to be rearranged. A short bridge at Mountain

View, and a long one near Caldwell, and marginal roads would be needed.

The pipes of the Newark and Jersey City water supplies would be submerged. Before submerging them, they should be most carefully inspected and put in permanent condition. With this done there is a probability that they could be used submerged for a long term of years. At some remote time, if it were necessary to renew the pipes, the Newark lines could be rebuilt on a location passing through Pompton and north of the reservoir, and the Jersey City lines could be replaced by a line passing near Mountain View and carried under the reservoir in a deep pressure tunnel at a point where the reservoir is narrow. The Catskill Aqueduct of New York City was carried under Croton Reservoir in this way.

Notwithstanding all these developments, it is still possible to build this reservoir and secure what is naturally the nearest and cheapest supply of good water.

There would be some incidental advantages in this reservoir. Many square miles of marsh land that are wet at times, and objectionable as mosquito breeding grounds, would be permanently flooded.

The storage capacity above the spillway would be sufficient to take care of any flood. If this reservoir had been in service in 1903 the great flood would have raised its water level temporarily about 7 feet, and there would have been no flood in the valley below. When the work done by Dayton and other cities is considered, to remove the danger of floods no more destructive than Passaic floods can be, the importance of this feature is apparent.

The construction of the Passaic Great Reservoir is not entirely a question of engineering. It depends upon whether the value of the real estate and the amounts which would have to be paid to acquire it have now gone to such a point that it would be cheaper to secure additional water from some more remote source. The works for the more remote source would cost more but the land would cost less. They would also afford no flood protection to the Passaic lower valley.

Water taken from the Great Reservoir could be filtered and pumped at Little Falls. Pipes would lead to points where water is required. Looking to a more remote future, and to the large quantities that may then be required in the southern part of the District, a tunnel from a point in the reservoir near its southern end at Chatham to some point on the eastern slope of Watchung Mountain would serve to give a more direct line and a cheaper delivery for large future quan-

tities required in the south. Or the filters and distribution could be made practically identical with those proposed in a subsequent section for the Long Hill Reservoir. In this case the water would be pumped to the filters.

From a sanitary standpoint, it must be considered that there is already a considerable population on parts of the Passaic catchment area, and that this population is certain to increase. The area is too large and too valuable for complete purchase. Intercepting sewers on the eastern side of the reservoir leading to disposal plants below Little Falls would aid in keeping the reservoir clean.

Filtration of the water would be necessary, and with all other means for preventing pollution would be sufficient to insure good water for a long term of years or permanently.

As long as this water was used as the most important supply of domestic water in the district, it would be desirable to keep people off this reservoir. The land around it would be owned by the water supply authority, and summer cottages, boating and fishing would be prohibited, or at least very closely restricted. Fluctuating water levels would be necessary, and this would make the shores somewhat less attractive.

Looking forward to a remote future when the density of population is much more than it now is, and to a time when ideas as to the qualities of water supplies may be much more exacting than they now are, it seems well to acquire rather large areas of land in advance of construction, and before the advances in land values sure to follow construction have taken place, and to protect forever from encroachment the areas from which water for domestic uses is to be taken. The procedure need not be uniform with respect to all the areas. It is more important to control the areas about the points from which water is directly taken than about remote parts of the system.

Under other conditions which have been considered as possible, namely, that some other source would ultimately become the primary source of drinking water, the Passaic Great Reservoir might then become a great supply of industrial water to be served without pumping and without filtration but with chlorination at a lower pressure throughout the industrial district. In this case the lake would be available for boating, fishing and swimming; and it would form a land and water park of great value to the District.

In connection with the water otherwise obtained from wells and other surface supplies, the Passaic Great Reservoir does not fall far

short of being able to meet our estimate of the required capacity 50 years hence.

This development is somewhat less attractive because of the partial development of tributaries by Newark, by Jersey City and by the North Jersey District Water Supply Commission. Whatever amounts have been or will be made available by these works would hardly add appreciably to the total quantity; and the amounts so obtained, or to be obtained, must be deducted from the amount that would otherwise to be added to the supply of the District.

The construction of such a reservoir seems to have been first suggested after the great flood of 1903. A lower flow-line was then proposed for flood control only. The reservoir is capable of serving the double purpose of preventing floods and of furnishing water supply; but to be used for both, the flow-line must be carried to the level now proposed. The combination is practicable from an engineering standpoint, and the design should be made to serve adequately both purposes.

Some years later studies were made for the use of a part only of the reservoir, with a dam at Mountain View. It was proposed to build a dam at this point forming a reservoir extending to Pompton, but leaving the southern or Chatham end of the basin undeveloped. It was also proposed to put the flow-line somewhat higher to secure the necessary storage for the northern streams.

This project was not carried out, and since that time there has been a great building development on Pompton Plains in the area that would be submerged.

If a part of the reservoir were to be left out to-day, it would seem more logical to use the southern part and leave the northern part unflooded. The southern part is larger in storage capacity, but deficient in catchment area. The dam site is not particularly good, but the required dam would not be very high, and it would probably be found possible to build an earth dam of large section that would be stable. Much less water would be made available.

Partial Passaic Development by Storage on Tributaries

If the Passaic Great Reservoir is not built, then each of the tributaries capable of development may be used separately to its economical limit. A study of this was made by Mr. C. C. Vermeule, and is found in the annual report of the State Geologist for 1909. The ultimate capacity that could be developed in this way was estimated at 400 mgd. This estimate was based upon the use of reser-

voir sites in the State of New York, and upon complete developments of the Pequannock, Rockaway and Wanaque Rivers, going in each case beyond anything now proposed. There are economic limits to development that are not precise. It may be doubted if it will pay to build all the storage then proposed. The Ramapo is limited to rather small reservoir capacities, if the state line is not crossed. We may now consider another limit, namely, that if the Passaic Great Reservoir is not built, that part of the catchment area above Millington may be otherwise used.

One thing is clear: If all the tributaries are developed and used to their limit, the flow of the main river will be so far decreased that the rate of output at the Little Falls plant of the East Jersey Water Company cannot be maintained, and at the same time, permit the supply of water that is taken as a basis of these estimates to flow through Great Falls and Paterson.

It is not the intention to set an exact limit on the amount of required flow in the lower Passaic. Many things would have to be considered before this limit could be wisely set. But it is clear that there must be some limit, and the amount now used as in the preceding section is 80 mgd. If this is larger than needed, then all the estimates of maintainable capacity of the Passaic may be correspondingly increased.

This 80 mgd., would include any water taken by the Morris Canal from the Passaic catchment area in excess of that brought into it from Lake Hopatcong as long as the canal is operated. Of the required 80 mgd. at Great Falls approximately 60 mgd., as an annual average, would be released at Little Falls and the remaining 20 mgd. would be contributed by 24 square miles of additional catchment area draining to Great Falls.

Little Falls Filters

The Little Falls filters have delivered water fully meeting the requirements of present standards. Nevertheless, dissatisfaction has been expressed by takers in one community. The principal ground for dissatisfaction appears to be the general use of the river for public bathing in a stretch above the plant.

If this plant is to be continued in successful and increasing service through a long term of years, it seems desirable and even necessary that some means of controlling this bathing should be found.

Combination of Wanaque Reservoir and Little Falls Filters

One way to get better raw water for the Little Falls filters would be to make use of the Morris Canal and one of its feeders to take water from the Pompton River at Pompton Plains to the Filter plant, a distance of about eight miles. The canal would need to be rebuilt to enlarge its carrying capacity. It is possible that this might be done with the canal in service. It could certainly be done if navigation were abandoned.

The area tributary to the Pompton River above the point where the canal feeder leaves it at Pompton Plains, including the Wanaque River and Greenwood Lake, but not the Pequannock River, is 289 square miles. This is 55 per cent. of the total area of the Passaic above Little Falls excluding the Rockaway and Pequannock. The remaining 45% of the area might be used to furnish, so far as it was able, the required 80 mgd. for the benefit of industries and for keeping the lower river clean.

There are several villages upon the Pompton River and its tributaries above the proposed point of intake at Pompton Plains. These are mainly located within a few miles, and it would seem possible to build sewers that would take the wastes from them to disposal plants below the intake. The wastes from Suffern and other communities in New York would, of course, go after treatment to the Ramapo River, and would not be reached by this procedure.

If the Wanaque reservoir were used in this way, it would be possible to use the Pompton River flows up to the capacity of the Little Falls plant whenever they were available, and otherwise to draw from the Wanaque Reservoir. The Reservoir, being relieved of the necessity of maintaining the draft for a part of the time, could furnish correspondingly more water when it was used. The Wanaque reservoir would sometimes furnish water to maintain the assumed 80 mgd. at Great Falls. Even so there would be a material addition to the capacity of the combined system over the capacities of the parts used separately.

The Pompton River between Pompton Plains and Two Bridges, at certain seasons of the year, would have only a reduced flow, but it is not apparent that any serious injury would result. The flow from Two Bridges to Great Falls and through Paterson is more important, and this would be maintained.

Developed in this way the ultimate capacity of the Passaic River without Millington is estimated as follows:

Newark—Pequannock	= 57	mgd.
Jersey City—Rockaway	= 57	"
Combined Wanaque and Pompton River taken by either river or canal to Little Falls	= 126	"
Sum	240	
Flow maintained at Great Falls for the benefit of the industries, etc.,	80	mgd.
Total development	320	"

If the Ramapo Reservoir were built as proposed and used in the same way as the Wanaque, it would add 33 mgd. to the combined capacity.

It would be possible to add something by further development of the Rockaway catchment area. No plan of doing this has been suggested, and it has not been thought necessary for the purpose of this study to make a plan, even in outline, for the further development of this source.

In comparison with this, the amount obtainable by the complete development of the Passaic without the Millington area, but with the Wanaque Reservoir built and with the same flow maintained at Great Falls, is 637 millions. With Millington otherwise used, the construction of the Great Reservoir would still add 397 mgd. above what can be fairly expected to be reached by separate developments. This is an approximate measure of the permanent inevitable sacrifice in capacity if the Passaic Great Reservoir is not built.

Long Hill Reservoir Fed by Northern Streams

Northern New Jersey has wonderful reservoir sites. And, of all that we have found, none is finer than the one now called the Long Hill Reservoir on the head waters of the Passaic River above Millington.

Long Hill is a narrow ridge of trap rock, 8 miles long, with a single narrow cut through which the Passaic River and a branch railroad run. Back of this is a great valley with a floor that is almost level. The hills of Morristown and Bernardsville are at the back, and a terminal moraine of ample proportions, extending from Morristown to Chatham marks the northern limit of the reservoir.

At the level of the proposed water line, where it is thinnest, it is half a mile through this moraine; and most of the way a mile or more. Some of the material of this moraine is sandy and gravely

in character and pervious, and some water will no doubt seep through it and be lost to the supply. This will increase the ground water supply now obtained from wells on its lower eastern slope or it may find its way to the Passaic River. Where the moraine is narrowest a possible water slope of between 2 and 3% would be found, and this is sufficient to carry a considerable quantity of water if the material is all sand. Dr. Kummel advises that much clay is to be expected mixed with the sand in the greater part of the moraine, especially in that part between Convent and Chatham.

It is not anticipated that the amount of water to be lost by seepage in any part of it will be serious; but the matter should be studied by borings and ground water levels before the reservoir is built. It is possible that some cutoff works may be required.

A dam on trap rock 110 feet high and 850 feet long at the flow line will flood an area of twenty-four square miles. A small dyke at the south will be needed. This dam is very small in comparison with the immense body of water controlled, and its construction presents no difficult engineering problem.

The whole basin is deep, and the amount of water to be held is 328 billion gallons. This is more than twice the size of the Ashokan Reservoir supplying New York City and so far the largest water supply reservoir in the world.

Of this amount, 182 billion gallons are held in the upper 40 feet and are considered available. The rest would be used in case of need by the aid of booster pumps.

This reservoir site is surprisingly near to the center of the water supply district. A pressure tunnel, 19 miles long, driven in the rock under the Passaic Valley and Watchung Mountain to Newark and Jersey City would deliver water directly through connecting pipes to the whole district. In elevation 320 feet above sea level the reservoir is sufficient to serve all but high service districts by gravity.

The one difficulty of this marvelous reservoir site is that there is not enough water to fill it. This defect can be corrected by driving a tunnel to make certain streams of the northern part of the state tributary to it.

The country northwest of this reservoir site is a series of ridges and valleys that succeed each other with great regularity. The valleys are five or six miles apart. They all slope to the southwest. They are all high enough at selected points to deliver water to the Long Hill Reservoir. Some of them have splendid reservoir sites

of their own, and these reservoir sites will be utilized to the extent of holding back flood flows long enough so that they can be taken to the Long Hill Reservoir by tunnels that need not be excessive in size.

A tunnel from the Pequest River crossing successively the Musconetcong, the South Branch of the Raritan, Black River, and the North Branch of the Raritan, is only twenty-three miles in length to Long Hill Reservoir. This length does not include several stretches where reservoirs are made to do duty as parts of the aqueduct. Ten miles of additional tunnel of smaller diameter would serve to bring the waters of Flat Brook, Paulinskill and Beaver Brook to the system. In this way a total catchment area of 645 square miles may be made tributary to Long Hill Reservoir.

Figures 4 and 5 (pages 40 and 41), show the plan and profile of the Long Hill Reservoir System.

The reservoir capacity is so large that most of the stream flow can be made available for use. This will amount to almost one million gallons daily per square mile, or, to 644 mgd. for the entire system.

Allowances must be made for water needed to maintain the Morris Canal, the industries and other necessary uses on the streams below the several points of diversion. Making a liberal allowance for all possible drafts of this kind, and for all losses by leakage that there may be, and for any changes in location that may be necessary with more complete study, and that may reduce the catchment area, such as for instance, going up stream to get better dam sites, it is clear that Long Hill Reservoir can be developed to yield more than 600 mgd.

Our estimate is 619 mgd., but like all estimates of water quantities based on existing data, is to be regarded as an approximation and not precise.

This added to the supply obtained from the Passaic River and its tributaries, and from wells and other local sources will more than cover the amount that we have taken to be provided 50 years hence.

This project, considering its magnitude and its nearness to the center of population would interfere with only a small amount of developed property.

There has been some choice of locations, and, in exercising this choice, we have tried to keep away from settlements. Only a few small villages would be taken. No large industries would be affected, but a number of grist mills would have to be acquired.

The approximate numbers of dwelling houses in the submerged area in Long Hill Reservoir and in all the the reservoirs tributary to it are as follows:

Long Hill Reservoir	477
North Branch "	15
South Branch "	51
Musconetcong "	52
Pequest "	30
Beaver Brook "	53
Paulinskill "	69
Flat Brook "	34
Total	781

In addition, there are found in Long Hill Reservoir the water supply system of Bernardsville, a large trap rock quarry, several

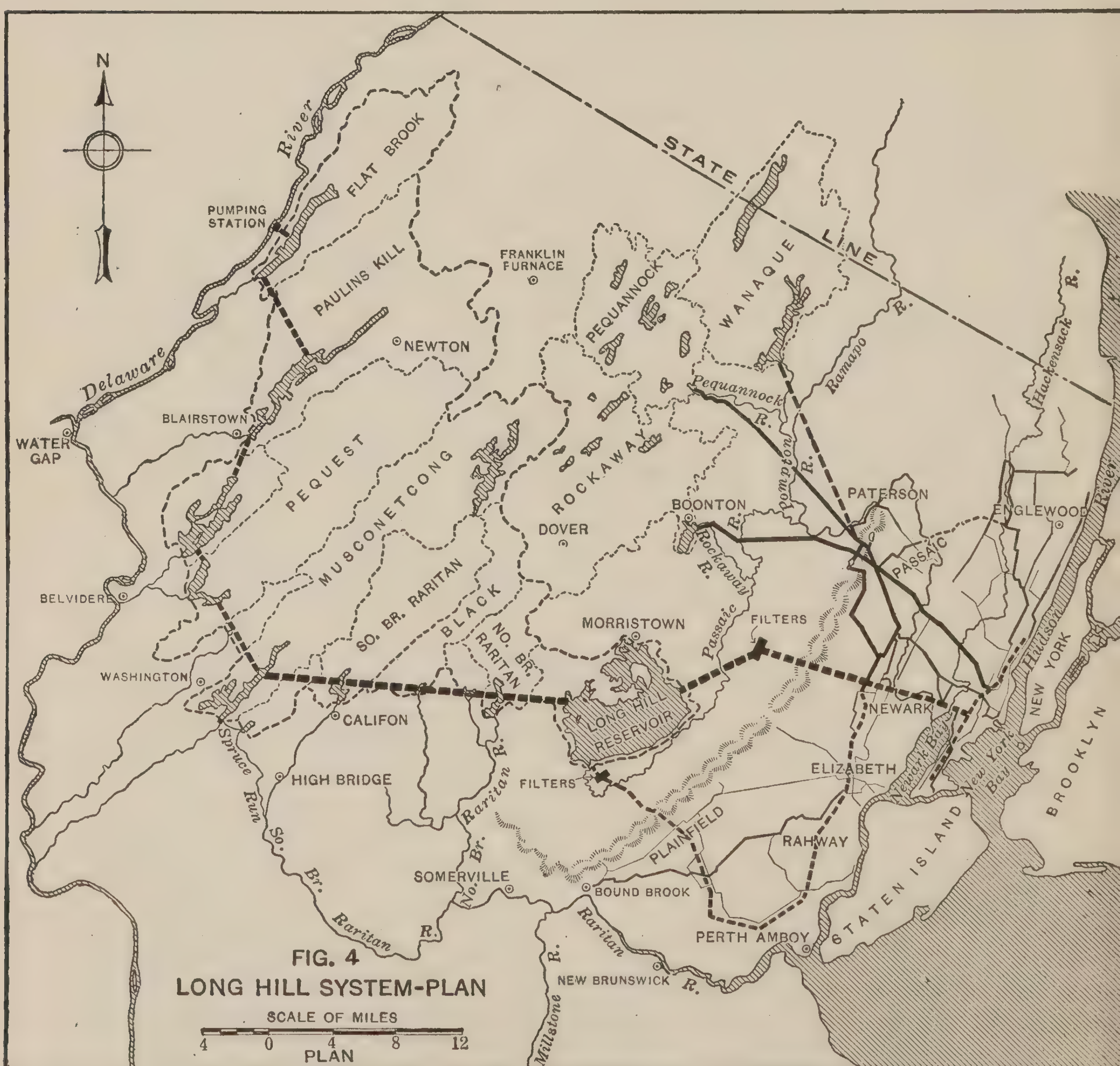

FIG. 4
LONG HILL SYSTEM-PLAN

grist mills, green houses, etc. In the Musconetcong Reservoir there is an oil pumping station which could be moved a short distance beyond the water shed line. The lower part of the fine old

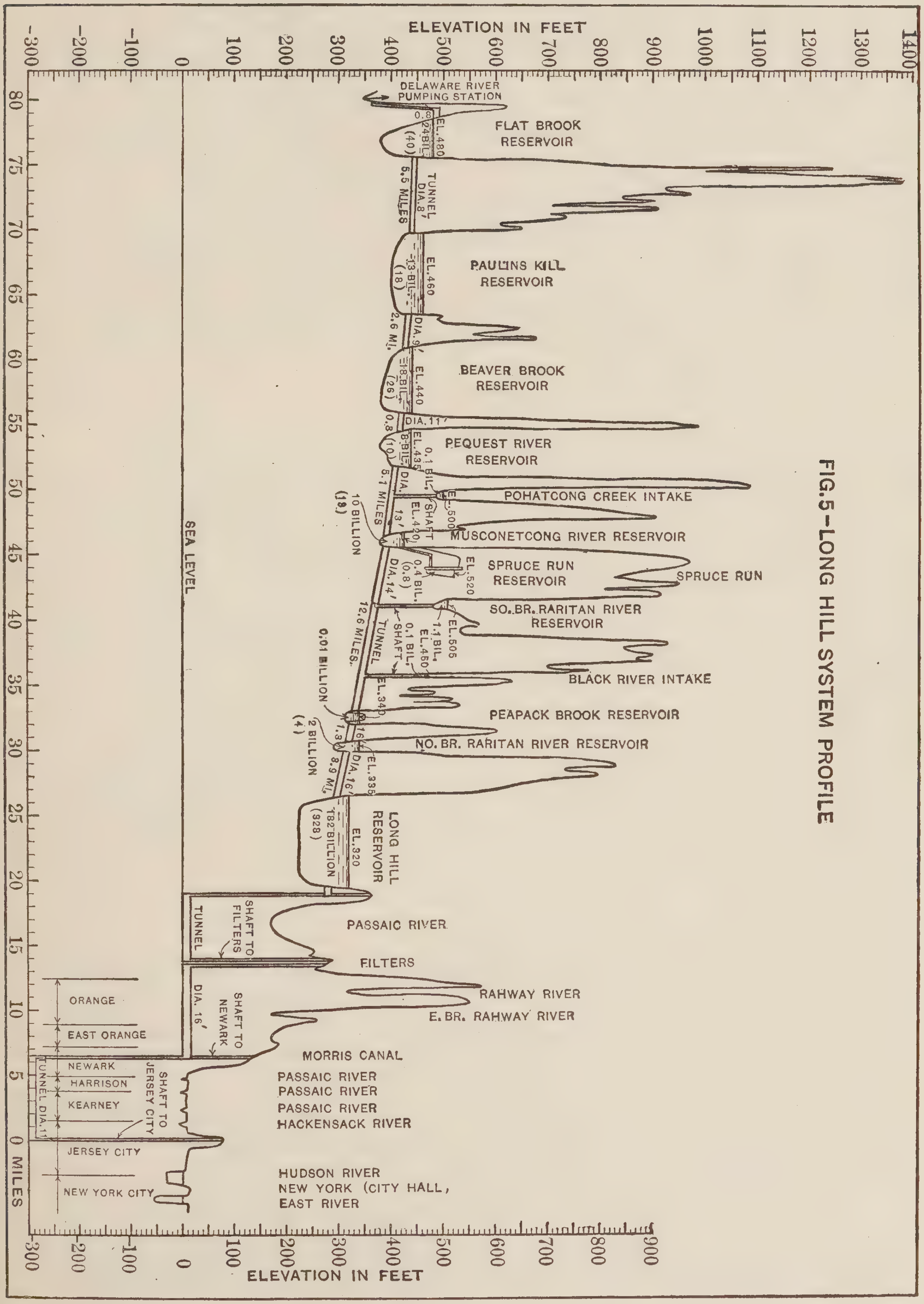

FIG. 5—LONG HILL SYSTEM PROFILE

Village of Hope on Beaver Brook would be submerged, leaving many of the old stone buildings on an island.

The total population in the submerged area, allowing five people to a house, is about 4,000, and all the houses and industries may be taken roughly as corresponding to those of a community with this population.

About 40,000 people live on the entire catchment area of 645 square miles and of these about 10% are in the areas to be flooded. This population has not increased in the last twenty years.

A small part of Morristown naturally drains towards the Long Hill Reservoir. It is completely sewered, and the sewage is pumped to disposal works outside the catchment area; but it would be well to remove some of the houses in Morristown on low ground nearest to the reservoir for the purpose of giving protection to the quality of the water.

Wallkill and Other Possible Additions

The Wallkill River in the northern part of the State is capable of being brought into the Long Hill system. A catchment area of 126 square miles would add 100 mgd. of water by gravity. A tunnel four miles long would take it to the Paulinskill Reservoir.

There are practical difficulties in the way of this addition. They may not be insurmountable, but it will not be considered further at present.

In a similar way there are several other areas that could be diverted to the Long Hill system. They have not been included for the present, either because the cost of connecting them would be higher relatively, or because other and local uses are now being made of the waters.

Delaware River to Long Hill System

After developing as far as Flat Brook as described above, the Long Hill system can be further increased by a connection with the Delaware River. Flat Brook Reservoir is only a mile from the Delaware River and 150 feet above it. It would be possible to pump Delaware River water into the system, either continuously or during that part of the year when the flow of the River is ample, and in that way increase its capacity.

The proposed tunnels are arranged to carry nearly all the water of a moderately wet year to the Long Hill Reservoir. In dry years, even in winter, the tunnels would not be running at capacity.

By pumping Delaware River water to the Flat Brook Reservoir in the winters of dry years only, the effect of a succession of dry years in reducing the volume of stored water would be eliminated. In other words, the Delaware River winter flows would be used to guarantee the runoff from the gravity areas up to the extent of an average year or somewhat beyond it.

With the tunnel sizes now proposed and necessary for the gravity development 750 mgd. or more could be reached in this way. With larger tunnels, and with some of the reservoirs raised to hold more water, it would not be difficult, with the aid of the Delaware to double the output, or to deliver, say 1500 mgd. through the Long Hill Reservoir.

The problem is to find a market for so much water!

Raritan Supply.

To carry this out, a dam would be built across the Raritan River above Somerville, just below the point where the north and south branches come together. A long earth dam would be required but the height is not great. A dam to raise the water to elevation 140 is proposed. The greatest depth of water would be about 80 feet. The reservoir formed would have a water surface of 48 square miles, twelve times as large as Lake Hopatcong. Its capacity to the bottom would be 300 billion gallons, and with only 20 feet drawn, 160 billion gallons would be available. The reservoir has seven arms, all long and narrow, and at no place would there be a large open body of water like that in the compact mass of the proposed Long Hill Reservoir.

Figure 6 (page 44), shows in plan the Raritan System.

Two main railroads (shown on Plate No. 1 at the end of this report) cross the area to be submerged. New locations could be found for these, each crossing the reservoir at a narrow place on solid fill and following a new location not longer or more difficult than the present one. Several branch lines of railroad of less importance could be connected to give necessary service, especially between Flemington and Somerville.

A line of state road could be carried across the reservoir on solid fill, close to the New Jersey Central Railroad, and marginal and other roads built as required.

The land in the reservoir site, and in the ridges that would remain as peninsulas extending far out into the reservoir, is nearly all of

it farming land of fair quality, with little forest and with ordinary farm buildings.

Only one village would be submerged—Three Bridges, with a population of 400.

A masonry aqueduct following the contour of the ground would be built from the dam, a distance of 32 miles, to a terminal in the outskirts of Newark where water could be delivered about 80 feet above tide by gravity. It may be that some water for industrial purposes could be delivered by gravity, but otherwise pumping would be required.

If the water were used for domestic purposes, it would be desirable to own all the land about the reservoir and to filter the water.

If this water were dedicated to industrial purposes, less land would be needed, and the reservoir could be used to the fullest

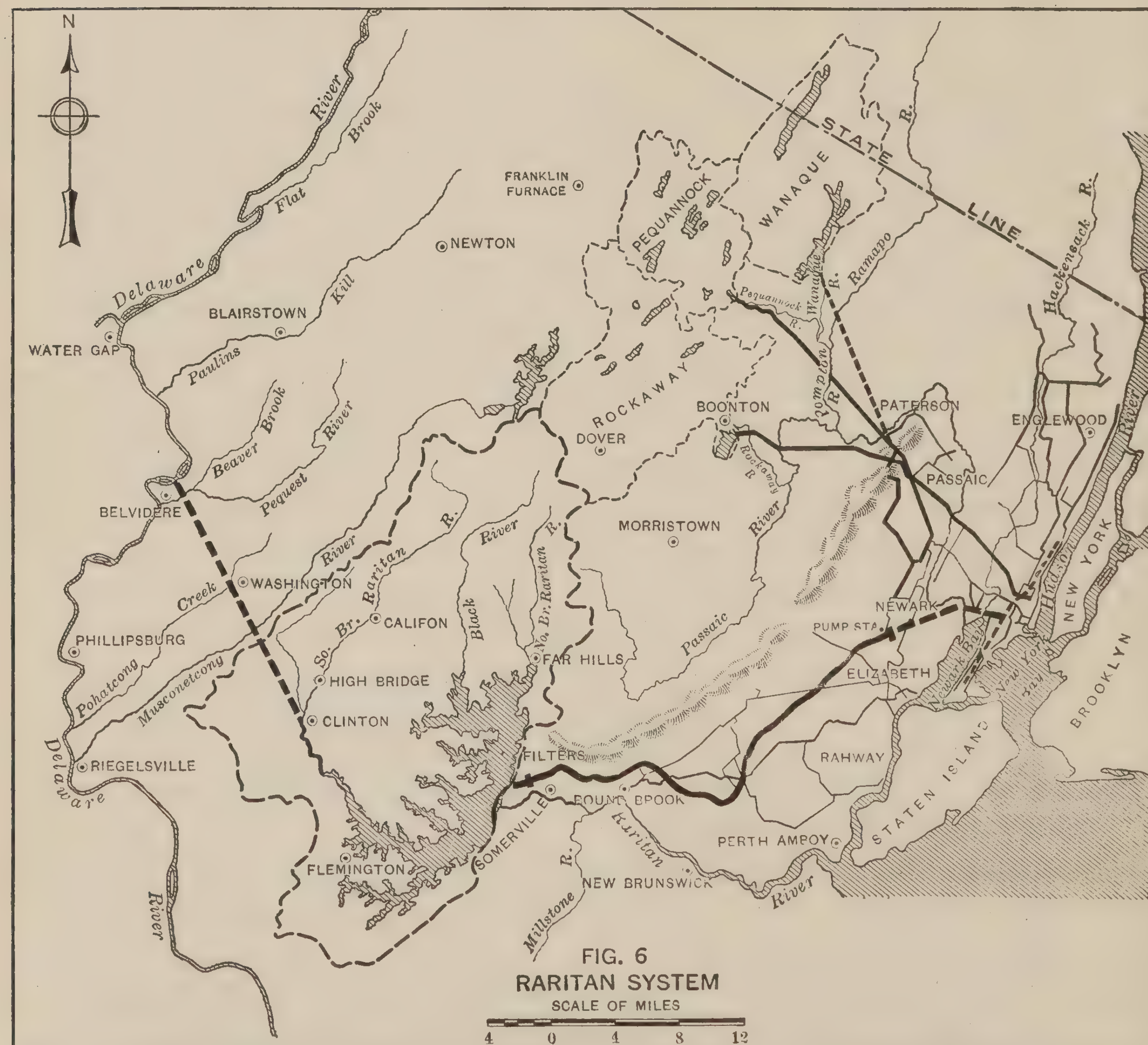

FIG. 6
RARITAN SYSTEM

extent for boating and swimming. Its topography, with seven long bays, adapts itself wonderfully to this use. No filtration would be necessary, and the water could be delivered by gravity at a slightly higher elevation, and at a somewhat lower price.

The peninsulas and surrounding lands would in any event naturally be devoted to forestry, and in the course of years this would add greatly to the attractiveness of the lake.

The catchment area is 468 square miles, and 429 mgd. would be available. Of this a certain amount, perhaps 15 mgd. might be dedicated to maintaining flow in the lower Raritan, if subsequent studies should show the need of it, leaving 414 mgd. available for water supply.

A part of the natural catchment area has already been covered in the Long Hill project. If the diversions contemplated in it were made the area tributary to this reservoir would be reduced to 343 square miles, and the amount of water available from it to 304 mgd.

This Raritan development obviously could be carried out to furnish, with filtration and pumping, water of full standard quality; and it may thus take its place in every respect with the other projects. But our thought has been that it might be better to develop it as a source of cheap industrial water for the remote future.

Delaware River to Raritan System

With this project under way, an almost indefinite increase in capacity could be secured by tapping the Delaware a short distance above Belvidere. A tunnel 17 miles long would bring water to the South Branch of the Raritan at Clinton. The available fall is 60 feet. A tunnel 12 feet in diameter would bring 400 mgd; one 16 feet in diameter would bring 800 mgd. The South Branch of the Raritan River and the Reservoir itself would furnish a large part of the connecting mileage of the conduit; and Delaware River water could be delivered in Newark by gravity in large quantities at a moderate cost. Clearly, with filtration, this also might serve as the basis of an excellent supply of almost unlimited extent.

Mullica and Wading Rivers

These two rivers drain part of the central southern flat forested section of the state. The water is soft with moderately high colors and could be made to serve as a basis of a most excellent water supply. At the point selected for consideration the combined catchment areas

are 412 square miles. Of this area about 100,000 acres called the Wharton Tract or 38% of the entire catchment area has been accumulated, and has been offered to the state at the very reasonable price of $1,000,000 or about $10 per acre.

It has been thought that the catchment area would be so largely controlled by ownership that water of superior quality could be obtained from it. To make this idea effective it would be necessary to purchase large additional areas, but it would hardly be feasible to acquire the whole catchment area. It is also to be noted that the village of Hammonton and other smaller villages are upon the area, and it would hardly be feasible to remove them, and indeed I do not think it would be necessary to do so.

To develop these sources, two dams would be required, each some 4 miles long, forming reservoirs with flow-lines 40 feet above tide. A canal cut through a ridge between would join the two reservoirs. The canal would be continued to the northward, as far as the elevation of the ground permits.

The combined reservoir thus formed would have an area of 54 square miles, an average depth of 12 feet, and would contain 140 billion gallons, of which 106 billion gallons would be available in the upper 15 feet.

Figure 7 (page 47), shows a plan of this reservoir.

The water would be pumped through rising mains about 12 miles long to a point on the ridge near Woodmansie where it would be filtered. From that point an aqueduct would be built to Newark. This aqueduct would be a concrete gravity section for most of its distance, but with occasional stretches of steel or other equivalent pipe where the ground is not high enough to carry an aqueduct. The total distance from the proposed pumping station to the outskirts of Newark is about 84 miles.

Plate 1 (at the end of this report) shows the general location of this aqueduct.

The pumping lift at the first pumping station, including friction, would be about 200 feet. Most of the head would be used up in the filters and in the aqueduct. It would be possible to deliver water in the district at about elevation 80 feet, that is to say, at the same elevation as water coming by gravity from the Raritan Reservoir. The route for the last few miles of the aqueduct is common to the two projects, and the terminal conditions would be identical.

The aqueduct would need to be 13 feet in diameter to carry the estimated output of 316 million gallons daily with a fair excess

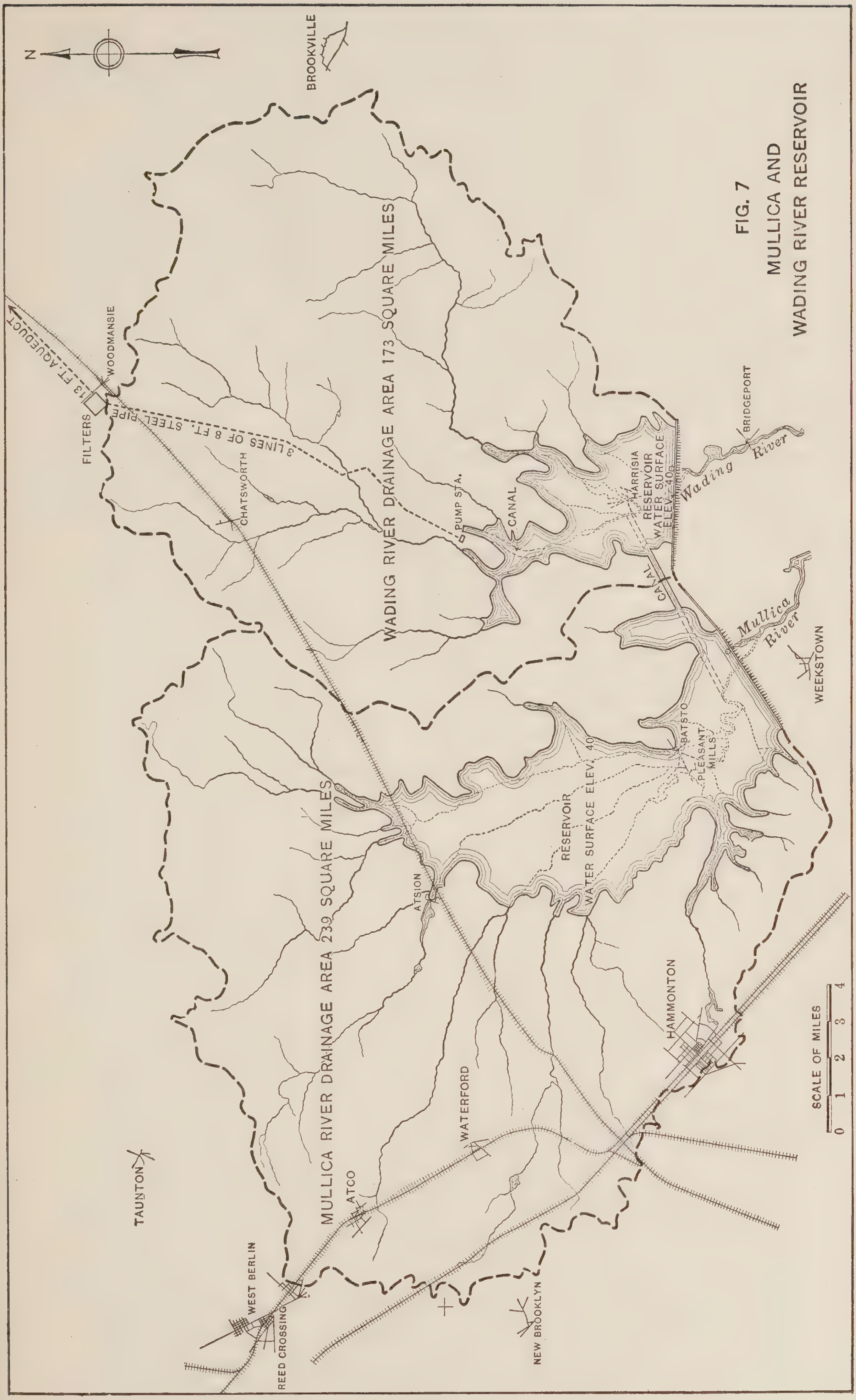

FIG. 7
MULLICA AND
WADING RIVER RESERVOIR

capacity for peak loads. The rising mains might be three lines of steel pipe, each 8 feet in diameter to be built one at a time as the growth of the business required.

This represents a complete development of these two streams, but there are other streams of more or less similar character that could also be developed. The Great Egg Harbor River lies next to the southward, and could be diverted to the Mullica River Reservoir and used in connection with it. There would be added expense because of the extra distance; and the water of this river is at present used for water power and manufacturing purposes at Mays Landing. Other possible streams are smaller in size.

It is also to be said that the development of the unequalled beaches along the ocean front in the southern part of the State will some time require much greater water supplies, and sufficient southern areas should be reserved to guarantee all future requirements of the shore settlements as well as the inland towns and industries.

This completes the description of the main supply works that have been considered, up to the point of distribution.

6. Distribution

The main problem is to find water to distribute. The manner of its distribution need only be considered in general terms.

The Long Hill reservoir if built will furnish gravity service to much the largest part of the District. Ground above Elevation 200 in Montclair, the Oranges and elsewhere will have to be placed in high service districts. The high ground along the Hudson River from Hoboken north will also require high service. Water for high service districts may be pumped from low service pipes at various places. This will all work out easily, for the most part following the lines of the present developments.

Top Water of Reservoir Only Included

Only the water in the upper forty feet of Long Hill reservoir has been considered as available for maintaining the supply. The minimum water level for distribution would be at Elevation 280. Many years would elapse before all the storage capacity of the upper forty feet would be required, and during this period the water would always be available at a higher level. Added elevation means that smaller pipes and higher velocities may be used, and money saved in piping, and also in high service pumping. With this in mind it is proposed to place the filters so that filtered water ready for distribution will be available at Elevation 280.

With this arrangement, between twenty and thirty feet of water in the Long Hill reservoir will be available by gravity through the filters. When the time comes that more storage capacity is required the water will then be lifted to the filters by booster pumps.

When the booster pumps are installed they will not be limited in their action to the 280-foot level. It is only a question of more horse power to reach additional storage in the lower part of the reservoir.

The additional capacity of the reservoir below the 280-foot level therefore has value as insurance against extreme conditions, and especially against a succession of dry years.

There is a similar reserve capacity in several of the upper reservoirs of the Long Hill system to be utilized in a similar way if it should ever be needed.

Pequannock for High Service

The Pequannock water is available by gravity at a higher elevation than any other part of the proposed supply. If the sources of supply were pooled, it would be good business to use Pequannock water for the high service only, thus avoiding pumping.

The Rockaway and the proposed Wanaque Reservoirs are slightly lower than the proposed Long Hill reservoir, but the differences are not enough to be troublesome. The water could all be used together in the same distribution system, using booster pumps on any of the supply lines where head was otherwise deficient. Water from Little Falls would also go to the same pipes with pumping.

The water supply of the district at the present time comes mainly through Great Notch. A point about four miles south of Paterson might be well called "Grand Junction"—so many of the present main supply lines pass through it.

Pressure Tunnel

The best method of connecting Long Hill reservoir with the district seems to be to drive a tunnel in the rock deep enough to be solid and strong, running to a point under Newark where a connection would be made with existing main pipes, and with other main pipes leading to other communities. From that point the tunnel, reduced in size, and following a nearly straight line, would be continued to Jersey City. There connection would be made with large pipes leading south to Bayonne and north to connect with the present main Jersey City supply pipes and with the Hackensack system at Hoboken.

The northern end of the district west of the Hackensack river would need but little reinforcement because the present main supply lines come through it, and with a few cross connections there would be ample capacity for many years to come.

Southern Loop

The southern part of the district is less adequately supplied with main pipes and new ones must be added. A large pipe line, starting at the distribution point in Newark and extending through Elizabeth to Rahway and connecting with the present 36-inch line from Bound Brook, would increase the supply in the southern part of the district.

This line may be extended all the way around through Plainfield, as a belt-line, and given an independent connection with the Long

Hill reservoir. This would pass through a region where additional quantities of water are likely to be required.

The amount of water coming through the southern side of the loop would probably always be a small percentage of the total output of the Long Hill reservoir, but even so, in the remote future the quantity might be large.

It is possible that the greater need of water in the near future in the southern part of the district would make it advisable to build the southern loop before the tunnel from Long Hill reservoir to Newark. Not much water could be delivered to Newark through this long pipe line, and the tunnel would soon follow.

As the Long Hill system is capable of being extended to a very large ultimate capacity the main pressure tunnel required to deliver it is large, larger even than the tunnel recently driven under New York City. And its cost is proportionately great. Ultimately the full capacity may be needed, and then the unit cost of delivering water through a very large tunnel will be low, but in the early years with a small part of the ultimate quantity delivered the unit cost will be high.

With a view to the requirements and limitations of these early years it may be better to reduce the size of this tunnel so as to anticipate only a moderate amount of growth, reckoned from the time that the tunnel is driven, and to supplement it later by a second tunnel or other means of distribution. This would have the advantage that the second tunnel or other means of distribution, when added, could be taken to that part of the District where the need of additional water was then greatest; and it is not possible to say at this time where that part will be.

This is a matter of design and need not be followed further at this time.

Figure 8 (page 52), shows the large present pipes of all systems in the District, with a rough outline of the proposed arrangements.

Water at Wholesale Only

It may be assumed that water would be delivered at wholesale to the various communities and to the various companies by meter measurement. This is the practice followed by the Boston Metropolitan Water District. Each community and company would keep its own distribution pipes and its own customers. Each would use its own water supply to the extent of its capacity and the new water could be used to supplement existing sources.

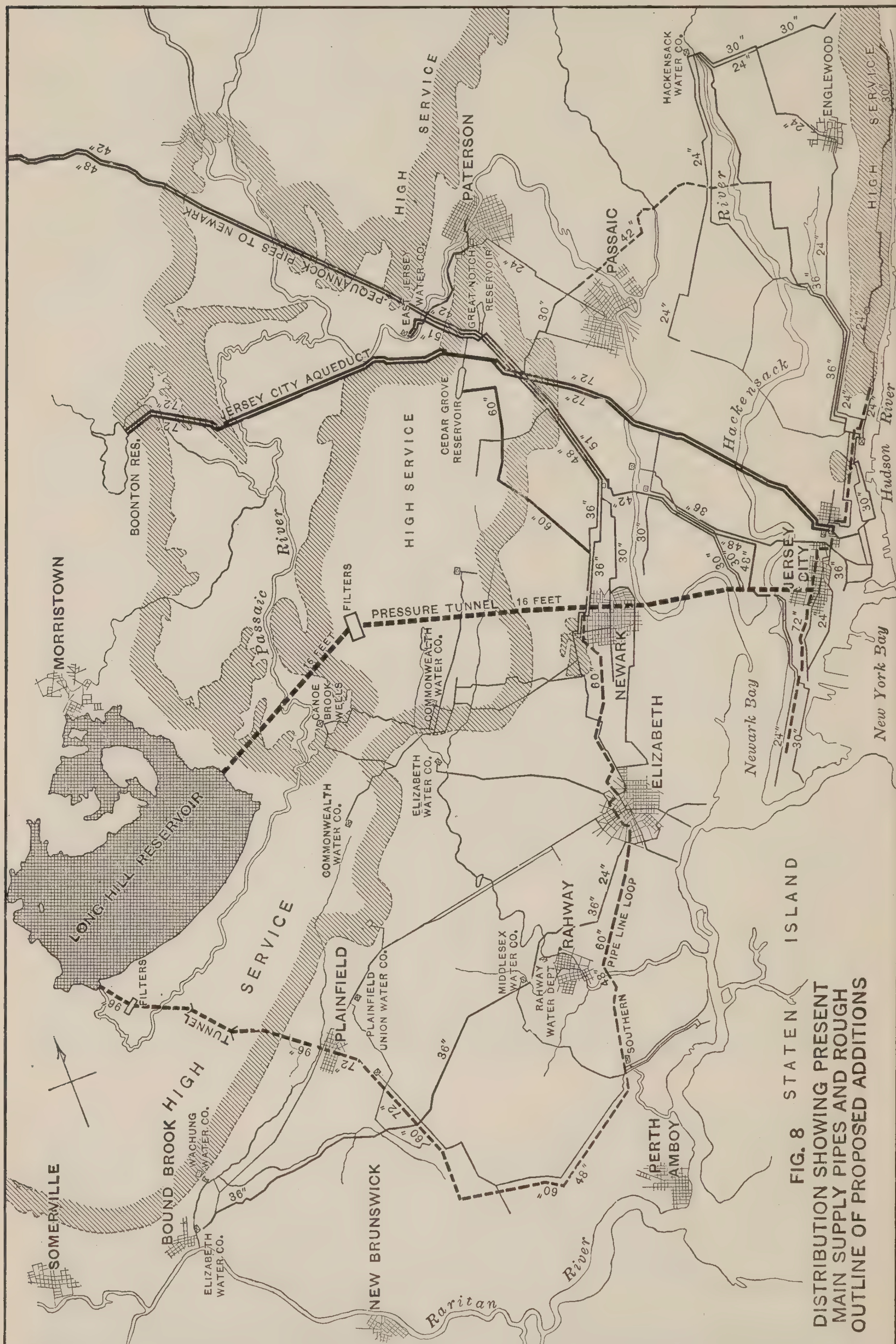

FIG. 8
DISTRIBUTION SHOWING PRESENT MAIN SUPPLY PIPES AND ROUGH OUTLINE OF PROPOSED ADDITIONS

Some Supplies to be Abandoned

It is to be expected that in a fifty-year period some of the present supplies will go out of service because of impairment of quality by increasing population upon the areas from which they are drawn.

It is not our present purpose to discuss the supplies that will be affected, or the times of their replacement, but the new works must have sufficient capacity so that there will be no embarrassment if such replacement becomes desirable.

Distribution from Other Sources

If the Passaic Great Reservoir were the main source of supply, filters could be located at Little Falls, with a pumping station to lift the water to the required service level in the manner now used by the East Jersey Water Company.

An alternate arrangement would be to drive a tunnel from the reservoir to some convenient point of distribution on the eastern slope where filters and pumping station could be located. Such a tunnel might take the water from the southern end of the reservoir. Although the reservoir would not be as deep at the southern end, it is not proposed to draw the water in the reservoir by more than 20 feet under any conditions, and the whole available quantity could be drawn from the Chatham end.

A Raritan supply coming from the south would reinforce the southern part of the District first. The water would all have to be pumped, and suitable service reservoirs built to be connected with the system.

Dual System of Water Supply

As much water is required for industries as for domestic purposes. No one source will be enough to meet all requirements. Different sources will be used, and from these waters of different qualities will be obtained. Waters that are undesirable for domestic purposes may still be suitable for industrial uses.

Why not have two grades of water like the two grades of milk? Grade A water to be used for the primary system and for all domestic purposes, and Grade B water to be used for industrial purposes? Grade B water might be drawn from some of the existing works now used for public supply after the encroachment of population has made the continued use of water from them for domestic purposes undesirable. The industries served would be mainly on

the lower levels, and within certain limited districts, and the piping required to reach them would not be a duplication of the whole system. Grade B water might be heavily chlorinated so that there would be little valid ground for objection to it for sanitary reasons.

Grade B water supplied at lower pressure and at a lower price per thousand gallons might at once aid industry and afford a market for waters that are not suitable for domestic requirements. It would take the place of a part of the Grade A water otherwise necessary.

Such a dual system has been frequently proposed but rarely adopted. Paris, France, and a few other European cities have long used it. At Rochester, N. Y., there has been an industrial supply of inferior quality sold at a lower price per thousand gallons.

In this case there is the beginning of such an industrial system in the Dyers' pipe line in Paterson, which is not classed as one of the public water supplies of the District.

Such double systems of piping have not been favorably regarded in American practice. It has usually been found that the interest on the cost of the additional pipes amounted to more than the cost of an additional quantity of Grade A water. But in this case the quantities will be large, and the rule found for smaller systems may not hold. Grade B water may be available in large quantities, and there may be old pipes that go with it that would carry it part or all the way to the factories. Adopting this plan would furnish a permanent outlet for most of the low grade water now used in the District, and would reduce the amount of new high grade water that must otherwise be provided.

7. Quantities of Water Available

An effort has been made to estimate the quantities of water that could be realized from each of the proposed developments, with all the accuracy possible from existing data.

The areas have been marked off and measured on state maps, one mile to the inch, with adjustments for shrinkage or stretch in the individual map sheets. The areas so found have been compared with values previously stated where available. Where they have checked approximately the accepted figures have been used. In one case only do our figures differ from the accepted values. After careful checking we use our own values of 785 square miles for the Passaic at Great Falls, and 761 at Little Falls. This is mentioned lest some one should think that we had made an error. The difference is not surprising when it is remembered that the New York Sheets of the Government map were not available when the commonly accepted values were determined, and the old maps may not have been very accurate.

The capacities of the reservoirs shown in Table No. 4 (page 22), have also been computed from the measurements of the state maps. A mile to the inch map is hardly sufficient to furnish an accurate basis for determining reservoir capacities, especially small ones, and the values reached must be accepted as only roughly approximate.

The runoff data considered in arriving at an estimate of the probable runoff in each one of the catchment areas are shown in Table No. 5 (page 56), and graphically in Figure No. 9.

The Pequannock gaugings obtained from Mr. Morris R. Sherrerd, and the Passaic gaugings made by Mr. J. H. Cook have been given greatest weight. To the latter have been added the amounts of water taken from the river for water supply. The runoff from stations in Pennsylvania, New York, and New England have also been considered.

The percentage of water area represents approximately the average above the gauging station actually used during the record period, and not necessarily present conditions.

Three square miles of water area are taken as equivalent in producing power to one square mile of land area, and a correction for elevation in the rate of 0.64 inches of runoff for each 100 feet of average elevation has been made. The average elevations of the

TABLE No. 5

RUNOFF RECORDS

	Year	Ending	Average per cent. water surface	Average elevation ground surface	Actual runoff inches	Runoff corrected for water surface	Runoff corrected for elevation 0.0064 x El.
Merrimack	37	1916	2.5	771 c	20.57	21.0	16.1
Connecticut	20	1899	0	1,172 c	19.58	19.6	12.1
Scituate	5	1920	2.0	457 b	28.03	28.4	25.5
Mystic Lake	20	1897	3.6	109 b	19.85	20.4	19.7
Cochituate	58	1920	7.2	180 a	19.49	20.5	19.3
Sudbury	46	1920	4.8	300 a	20.62	21.3	19.4
Wachusett	24	1920	5.3	750 a	22.83	23.6	18.8
Manhan	24	1920	0	965 b	26.22	26.2	20.0
Little River	15	1920	1.4	1,293 b	27.52	27.8	19.5
Nepaug	8	1920	0	754 b	24.91	24.9	20.1
East Branch	8	1920	0	1,022 b	28.13	28.1	21.6
Esopus	14	1920	0	1,984 b	32.07	32.1	19.4
Schoharie	18	1920	0	2,148 b	27.80	27.8	14.0
Rondout	14	1920	0	1,655 b	31.09	31.1	20.5
Catskill	10	1920	0	1,580 b	17.45	17.4	7.3
Hudson	29	1916	1.57	1,226 c	23.50	23.8	16.0
Croton	53	1920	4.2	600 a	22.60	23.3	19.5
Pequannock	27	1918	4.0	1,043 b	26.99	27.8	21.1
Delaware*	16	1920	0	1,458 c	23.12	23.1	13.8
Passaic	23	1920	1.42	603 b	25.75	26.0	22.1
Nishaminy	28	1912	0	345 b	22.65	22.6	20.4
Perkiomen	28	1912	0	540 b	22.58	22.6	19.1
Tohicken	29	1912	0	500 b	27.41	27.4	24.2
N. Br. Susquehanna**	19	1920	0	1,443 c	23.77	23.8	14.6
Susquehanna	26	1916	0	1,295 c	21.12	21.1	12.8

a—New England Water Works Association Committee.
b—H. W. & F.—U. S. Geological Survey maps, 1 mile per inch, exact.
c—H. W. & F.—U. S. Geological Survey maps, 37 miles per inch, rough.
* Above Port Jervis.
** Above Binghamton and near it.

various areas have been ascertained for this purpose and are recorded in Table No. 3 (page 21).

The corrected runoff decreases as the distance from the sea increases, and a base for estimate has been chosen with all the data before us.

As data of this kind continued to be received after our calculations had been made, additional results of a confirmatory nature have been recorded, but the calculations have not been revised where only small adjustments were indicated. Small inconsistencies will therefore be found in some of the figures.

The areas and the expected amounts of average runoff are shown in Table No. 3 (page 21), to which reference is made for the

values carried into Table No. 6, showing our calculation of capacity.

In laying out the reservoirs and tunnels of the Long Hill system the intention has been to make the sizes such that 98% of the total runoff from tributary areas could be taken to Long Hill Reservoir, so far as needed and not held back for other disposal. That is to say, only 2% of the total flows would occur in floods beyond the

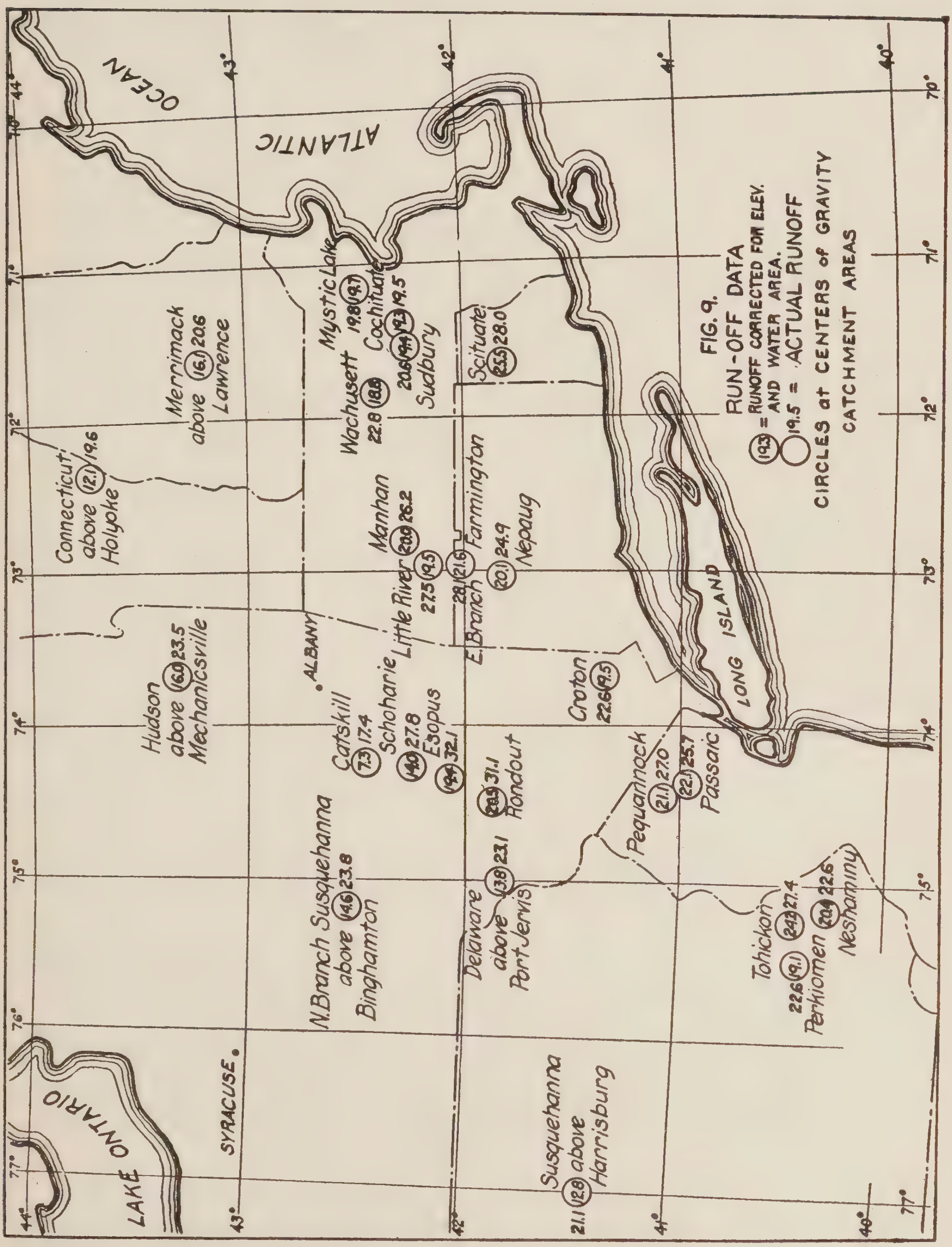

FIG. 9. RUN-OFF DATA

capacities of the reservoirs and tunnels. The basis of this calculation is set forth in an article by Mr. F. H. Hapgood, of our office, in *Engineering News Record,* Volume 85, page 153. The basis used is believed to be fairly applicable to this calculation.

In calculating maintainable capacities the methods described in a paper presented to the American Society of Civil Engineers, Volume 77, page 1539, have been followed, except that a few minor improvements have been made in some of the methods. The estimates now made correspond with Tables in the American Civil Engineer's Pocket Book, Fourth Edition, page 1196.

The co-efficient of variation for stream flow in New Jersey is taken as 0.24. This co-efficient is an indication of the variability of the climate, and of the possibility of the occurrence of dry years, and of successions of dry years. The value selected is probably slightly above the truth, but with limited data it is best to be safe.

Another important index of flow is the ground water storage. This is expressed as so many days storage. The Pequannock records indicate 30 days ground water storage. That is to say, for this stream the amount of storage to be provided is less than would be needed if the catchment area were all clay and rock by an amount equal to 30 days supply.

The Pequannock is the only New Jersey stream for which we have records capable of analysis to yield a value of this kind. Values for other eastern streams are given in the transaction of the American Society Civil Engineers, Volume 77, page 1615. The number of days ground water storage makes quite an important difference with the amount estimated as available for partial developments; that is to say, for such developments as the combined Little Falls and Wanaque on the Passaic River. Ground water storage varies from stream to stream, and the values used are based upon our own judgment. It is unfortunate that a few more New Jersey records are not available.

Starting with the Pequannock where the amount of ground water storage is known approximately from the records as 30 days, allowances for other streams are as follows: For all parts of the Long Hill Reservoir area 30 days; for the lower Raritan, the soil being less pervious—zero; for the Passaic, 30 days; for the Hackensack, 40 days; for the Mullica and Wading Rivers, 60 days.

With these assumptions and with the annual water crops shown in Table No. 3 (page 21), and the reservoir capacities shown in

Table No. 4 (page 22), the quantities that can be maintained from vairous areas and storage conditions are computed.

The estimates relate throughout to a 95% dry year. That is to say, they are made on the basis that by the best use of existing data it is probable that the full supply can be maintained for 95 of each 100 years. For the other five years there would be shortages. The

TABLE NO.6.-CAPACITIES of WATER SOURCES, PRESENT and PROSPECTIVE

CATCHMENT AREA	AREA, SQ. MILES	MEAN FLOW MGD	STORAGE BILLION GALS	STORAGE RATIO (CORRECTED)	% AVAILABLE	GROSS YIELD MGD	PRIOR RIGHTS MGD	NET YIELD MGD
Mullica and Wading Rivers	412	359	106	0.76	88	316	0	316
Raritan	468	493	157	0.84	87	429	15	414
Raritan, Less Long Hill System	343	343	157	1.21	93	319	15	304
Long Hill, Millington	55	44	182	11.1	99	44	2	42
" " to North Branch	80	73*	184	6.8	99	72	4	68
" " " Black River	117	115*	184	4.3	99	114	5	109
" " " South Branch	172	182*	184	2.74	98	178	10	168
" " " Musconetcong	303	333*	194	1.56	96	320	20	300
" " " Pequest	427	472*	202	1.15	93	439	22	417
" " " Beaver Brook	458	503*	220	1.17	93	468	23	445
" " " Paulinskill	583	640*	233	0.98	91	582	24	558
" " " Flat Brook	645	711*	257	0.97	90.5	644	25	619
Pequannock – Newark	64	82	10.6	0.34	69	57	0	57
Rockaway – Jersey City	119	146	7.6	0.14	42.5	62	5	57
Wanaque – Ultimate Devel'p't.	94	112	20.0	0.47	77	86	12	74
Ramapo – " "	147	181	6.3	0.09	33.5	61	15	46
Passaic with Great Reservoir								
with Millington								
Newark & J.City Res.	785	891	238	0.71	85	757	90	667
do & Wanaque Res.	785	889	258	0.77	87	773	90	683
do & Ramapo Res.	785	887	266	0.80	87.5	776	90	686
without Millington								
Newark & J.City Res.	730	828	238	0.76	86.5	716	90	626
do & Wanaque Res.	730	826	258	0.83	88	727	90	637
do & Ramapo Res.	730	824	266	0.86	89	733	90	643
Passaic without Great Res.								
Excluding Newark, J.City, &								
Millington								
Little Falls & Wanaque	547	645	20.0	0.08	32	206	80	126
do & Ramapo Res.	547	645	26.3	0.11	37	239	80	159
Hackensack	115	129	2.6	0.05	26.5	34	1	33
do, upon completion of work	115	129	4.0	0.08	33	42	1	41
do, assumed ultimate	115	129	10.0	0.20	54	70	2	68

* 2% deducted from mean flow to cover diversion loss.

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deficiencies would range from 1 to 10 per cent. (and possibly to more than 10% at very long intervals) and would average about 6% in all the years of shortage, these being 5% of the whole number.

Table No. 6 (page 59), shows the principal areas that have been considered; the annual water crops; the ratios of storage to mean annual flow; the amounts of water that can be realized from the storage at hand in each case; the allowances made for prior rights and other uses; and finally the net maintainable supply that may be expected from each source.

Estimates of this kind are not more accurate than the data on which they rest; and these data have limitations. It may be said of these estimates that they have been made on a consistent basis, and that it may be expected that the actual quantities, if the works were developed, would not be likely to differ by more than a few per cent. from the estimates given.

From the amounts so found have been deducted certain quantities under the heading "Prior Rights." For the Hackensack River this is represented by the amount that it is estimated that the City of Nyack, in the State of New York, will sometime require. For the Passaic River, with partial development, the allowance is 80 mgd., reckoned at Great Falls, and this must include whatever amount is taken out of the catchment area by the Morris Canal over and above the amount brought into it from Lake Hopatcong. For complete development of the Passaic River the same deduction is made, and in addition 10 mgd., to cover or replace water now taken from wells in Canoe Brook by East Orange, and by the Commonwealth Water Company.

For the Wanaque 12 mgd., are deducted this being the present requirement of your department, but I have taken this not as a rule for all time but as something that could be varied according to the needs of the time. It is assumed that this amount will also cover whatever amounts are drawn from this area by the Morris Canal, so that the allowance is taken to cover both the Morris Canal draft and all other water that may be required to be released.

For the proposed Ramapo Development an amount has been assumed, with reference to the need of letting enough water escape so that the Little Falls plant and riparian owners in Paterson should not suffer too severely.

For the Rockaway 5 mgd. are deducted to cover rights of the Morris Canal, and an amount to be diverted from the catchment area when the proposed intercepting sewer is built.

For the other estimates amounts have been entered in the table in view of conditions in the various streams. The amounts that it will actually be necessary or wise to release can only be determined after careful inquiry as the works progress and are operated. Some quantities will have to be released. What these quantities will be we do not know. These figures stand, for the time being, as representatives of the actual quantities. They may be close enough to them for our present purpose.

The amount of water obtainable by complete development of the upland sources is as follows:

	MGD.
Long Hill Project as far as Flat Brook	619
The Passaic as now developed, and with the Wanaque Reservoir added and with the addition of Great Reservoir, but not including water taken by Long Hill and leaving 80 mgd. minimum flow at Great Falls.	637
Raritan, not including water taken by Long Hill	304
SUM	1,560
Hackensack	41
Other present surface sources, so far as continued in use	20
Present Ground Water Sources	40
	1,661
Amount that might be added to the Long Hill and Raritan sources by diversion of Delaware water in winter, so as to completely fill reservoirs holding 635 billion gallons	839
Making a total that could be developed (250 days storage)	2,500

This is ten times the present rate of output.

8. Cost

You desire a general idea of the probable costs of developing water in large quantities from the various sources. A general idea is all that can be hoped for from such studies as have been made. We have tried to determine what land would be required, and what it would cost; who would be damaged, and how much would have to be paid because of such damages; what dams and reservoirs would be required, and what they would probably cost; and what aqueducts, pumping stations, filters and other equipment would be needed.

We are, of course, more or less familiar with the construction costs of such structures, but in this case we are handicapped by the lack of detailed studies necessary for estimates. Such studies were not possible within the limits that were set for our work.

The records of actual cost of construction of large water works systems, such as those built for the Massachusetts Metropolitan District years ago, and of the more recent Catskill supply for New York City, construction of which is still under way, have been helpful.

Mr. J. Waldo Smith, Chief Engineer of the New York Board of Water Supply, has exchanged data with us, and has furnished in convenient form an analysis of the cost of the Catskill aqueduct, and of the city tunnels that form parts of it, and which are comparable with the pressure tunnels proposed in some of the New Jersey plans.

Col. William J. Wilgus, formerly Chief Engineer of the New York Central Railroad has aided with suggestions as to the treatment of the railroads that would have to be raised and relocated to make way for the various reservoirs.

Estimates of compensation to owners of water power below the points of diversion have been made by a rough general method based on catchment areas and utilized falls, without refinements.

The figures entered in our schedules for dam and reservoir construction, made in advance of surveys and borings, take into account conditions that are apparent on the surface, and otherwise are based upon what we have learned from Dr. Kummel as to geological conditions.

The amounts allowed for real estate form a very large part of the totals. New Jersey land is good land and it has long been used for other purposes. The percentages of the whole estimates allowed for land are, so far as we know, larger than have ever been paid in

similar works. The estimates are rather of what we think it might cost to acquire the various sites, than of what we think the properties are fairly worth, and the costs of acquiring them are included. Experience of Water Boards in acquiring such properties on a large scale has been taken into account.

It may be pointed out that your engineers have no special knowledge of real estate values and their limitations in this respect are freely admitted.

Allowances have been made for the cost of moving old churches and cemeteries to suitable sites above the flow-line, and also for removing and replacing the various pumping stations, water sources, sewage disposal plants, quarries and other industries that could be moved to neighboring sites. These are intended to be sufficient to make all the properties good under new conditions.

The estimates for each proposed source are intended to cover the main pressure tunnels or their equivalent, to carry water into the center of the District, passing through Newark to Jersey City, but they do not include the lateral piping necessary to reach all the thirty-three water works systems, or so many of them as necessary.

Pumping stations where necessary to bring the water to the elevation of the Long Hill Reservoir are included.

TABLE No. 7

ESTIMATES OF COST, IN MILLIONS OF DOLLARS

	Passaic Great Reservoir	Long Hill System	Raritan	Mullica and Wading Rivers
Sites and damages	39	24	21	3
Dams and reservoirs	10	15	12	11
Aqueducts	0	0	21	44
Collecting tunnels	..	20	..	..
Pressure tunnels or equivalent	13	23	5	4
Filters	11	19	10	8
Pumping stations	4	2	7	13
Other structures	..	5	3	3
Engineering, Administration and contingencies	16	22	16	17
Total cost of works	93	130	95	103
One-half capitalized pumping cost	8	0	15	22
Total cost	101	130	110	125
Capacity Mgd.	450*	750	400	300
Cost per Mgd. capacity	$225,000	$173,000	$275,000	$417,000

* In addition to 200 mgd. now obtained and to be obtained from this source by smaller developments and not counting a flow of 80 mgd. assumed to be maintained at Great Falls for the benefit of manufacturers and the lower river.

Estimates for filter plants are included in all cases. The Long Hill Reservoir water would be of excellent quality without filtration, but we do not feel that it would be satisfactory to propose the use of unfiltered water for the future supply of the District.

As a further emphatic indication that these are only rough, round preliminary estimates, the amounts will be entered in units of one million dollars each in Table No. 7, which it is hoped will be enough for your present purpose.

It is not difficult to decide from an inspection of this table that the Passaic and the Long Hill sources are better economically than the Raritan and the Mullica and Wading Rivers. It also seems clear that these sources together are capable of furnishing all the water that it is necessary to now consider. Further consideration of the others may be safely postponed until the District has grown to be much larger than it now is.

In leaving them it may be stated that the Mullica and Wading Rivers have excellent points, but they are too far away. The Raritan would furnish an excellent water supply at a price that would be considered low if it were not for the still more advantageous possibilities close at hand.

As between the Passaic and the Long Hill Systems there is one important difference. The major part of the Passaic development would have to be carried out at once. The filters and pumping stations and some other equipment could be added progressively as needed, but the large expenditures for the site and all that goes with it, and for the dam and reservoir, would have to be incurred before any water became available.

The Long Hill System on the other hand permits a progressive development. In Table No. 8, a schedule is presented which shows successive steps. With each step is noted the capacity up to that point, and the cost per million gallons corresponding. A small pumping cost in the remote future is not brought into this statement.

It will be seen that according to this schedule when the capacity of the Long Hill System reaches a point equal to that of the additional capacity to be secured from the Passaic, the cost will not be very different. It has, however, two advantages: First, this point in the development may be reached by easy stages with works built from time to time to meet the requirements of the community; and second, that having reached this point the foundation has been laid for further quantities of still cheaper water to be brought in through the works already provided of a capacity to anticipate future growth.

As a water works proposition only, taking into account the greater elevation of the water, the absence of pumping, the smaller population on the catchment area and the possibilities of progressive development, the Long Hill System is distinctly more advantageous than the Passaic Great Reservoir.

But if in addition there is taken into account the advantages of flood protection and other incidental advantages of the Passaic Great Reservoir it is not so easy to strike a balance.

TABLE No. 8

SUCCESSIVE DEVELOPMENT OF LONG HILL SYSTEM

This is an analysis of the Cost Estimate arranged progressively. In comparing with Table 7, note that the allowance for engineering administration, and contingencies is here included as part of the amount shown for each item.

Long Hill Reservoir	$16,045,000	
Southern loop, extending to Newark with filters	7,410,000	
42 mgd. @ $558,000		$23,455,000
Filters for North Branch and Black River division	$3,000,000	
Reservoir and Tunnel	12,402,000	
109 mgd. @ $357,000		38,857,000
Pressure Tunnel, to Newark and Jersey City	$27,538,000	
Filters for So. Branch Division	1,560,000	
Reservoir and Tunnel	7,085,000	
168 mgd. @ $446,000		75,040,000
Filters for Musconetcong Division	$3,900,000	
Reservoir and Tunnel	10,939,000	
300 mgd. @ $300,000		89,879,000
Filters for Pequest Division	$3,240,000	
Reservoir and Tunnel	8,263,000	
417 mgd. @ $243,000		101,382,000
Filters for Beaver and Paulinskill Division	$4,116,000	
Reservoirs and Tunnels	9,981,000	
558 mgd. @ $207,000		115,479,000
Filters for Flat Brook Division	$1,680,000	
Reservoir and Tunnel	5,750,000	
619 mgd. @ $199.000		122,909,000
Filters for Delaware Division	$3,800,000	
Tunnel and Pumps	2,862,000	
750 mgd. @ $172,000		129,571,000

NOTE: In Table No. 8, it is assumed that the Southern loop, or a part of it, will be first built; and that the first water will be distributed through it; and that the pressure tunnel to Newark and Jersey City will not be built until somewhat later. In the interval it may be that there will sometime be more water available in Long Hill Reservoir than can be distributed through the Southern loop. This will depend upon how large that loop is made and what extensions of it there may be before the pressure tunnel is built. In this interval, if the Little Falls facilities permitted, water could be released from Millington to flow down through natural channels to the Little Falls plant and be utilized in that way.

This is another interesting matter. The yield of its own catchment area is so small that by itself years would be required to fill Long Hill Reservoir. With some of the feeders diverted to it the filling time would be reduced.

It may also be considered that if the growth of the district is to be very great, the time may come after more than 50 years when both systems will be needed, and if this is so, it would be wiser to build the Passaic Great Reservoir first.

There are some problems so deep that the first rapid study may not get all the points to be considered, and it may be well to leave something for further discussion.

Comparision of the Estimate of Cost of the Long Hill System with the Cost of the Catskill Supply of New York City

Two systems of water supply are never quite comparable. Attempted comparisions of things that are not comparable are difficult and often misleading. Notwithstanding the difficulties in the way, the comparison of the proposed Long Hill supply with the Catskill supply of New York City is so obvious, that some mention must be made of it. The comparison now made is very brief and it is recognized that many important things are not reflected by it.

The Long Hill system developed as far as Flat Brook, and without filters, would probably produce somewhat more water, and as good water as can be delivered by the Catskill supply when it is finished, but not including the filters that are proposed but that have not yet been built.

The amount spent on the Catskill supply to December 31, 1921, is about $150,000,000. Bringing the Catskill works to an equivalent position for comparison, including complete diversion of Schoharie Creek, the installation of additional pressure syphons, and paying damages for diversions of water which remain to be paid is estimated at about $30,000,000. The total cost of the Catskill system up to this point will then be about $180,000,000.

The corresponding cost of the Long Hill system, including engineering, administration and contingencies, but excluding filters, is estimated at $104,000,000.

The estimate for the Long Hill system is thus only 58 per cent. of that for the Catskill Works.

The difference is so great as to require an explanation. The explanation is easily found. The length of the main tunnels and aqueducts in the Catskill system from the Schoharie Reservoir to the Ashokan Reservoir and thence to Hill View Reservoir, and including the pressure tunnel under New York City to, let us say, a point where it is nearest to the City Hall in New York, is about

127 miles. The corresponding length of the tunnels in the Long Hill system (it is all tunnel in that case), from Flat Brook to Jersey City is 52 miles. In both cases distances in the beds of natural streams and in reservoirs are not counted. The Catskill aqueduct is thus 2.45 times as long as the Long Hill Aqueduct.

It may also be mentioned that work on the Catskill Works was started, and a large part of the work done, before the war, and before the advance in prices, and that, the Long Hill estimates are on a higher basis than Catskill average costs.

9. Suggested Plan of Procedure

The diversity of ownership in the thirty-three separate systems of water supply now in the District is such as to make it almost impossible to hope for an adequate solution by voluntary co-operation. Strong action in the interest of all is essential to success.

To provide additional water to fully supply the whole District for a term of years is not difficult from an engineering standpoint. From a financial standpoint it will not be burdensome to pay for the necessary works. The problem is to get co-operation or something to take its place. There is no community in the District that can carry alone an adequate project for the whole district, and there is no group of communities that can be reasonably expected to work together to do it.

The problem is more difficult because it has to be handled at long range. Great water works systems require a long time to build, and it is hard to get public interest and general co-operation with respect to a need that is not immediately apparent. It may take ten years to go through all the preliminaries and to build the works and fill the reservoirs and bring them to the point of actual delivery of water.

If the work is to be done economically and well it must be done deliberately. Haste means waste. If action is put off too long there is apt to be precipitate action in some dry season when the supply fails, or is near the point of failing, and we know from experience that communities are almost incapable of acting wisely under such stress.

You have asked for suggestions as to the procedure most likely to be successful and the following rough outline of a plan is presented.

Proposed Plan

Create a Water Board, having very broad powers, including the right to acquire existing sources of supply, and lands and rights for additional sources, and to build water supply works, to sell water at wholesale and to issue bonds to raise money to pay for works bought and built.

The Board might well be a State Board and in that case the bonds would be State bonds.

The requirements should be made that the business of the Board should be conducted so that all money spent would ultimately be recovered from its own operations. No contribution from general State funds should ever be permitted.

One of the most important matters is to get the best men in the state for members of the Board. A Board of three members is large enough. Men of affairs must be selected capable of handling large enterprises efficiently and economically. Men must be secured who are in a position to decide all questions on their merits and without obligation to anyone. The appointments must not be political, and the term of office should be for a long period, or for life. If it is made for a shorter term, it should be with the expectation of reappointment on the expiration of the term of service.

The Board, on being created, would proceed to take over some of the larger supply works now in service that are of a kind to form appropriate and advantageous parts of a permanent general system. It is not the intention to make a precise list of what these would be, but in a general way, it might include the supply works of Newark, Jersey City, of the East Jersey Water Company, including the whole of Little Falls plant, and also the works of the North Jersey District Water Supply Commission on the Wanaque now building. The Morris Canal property or parts of it may be considered tentatively to be included among the properties to be acquired in case navigation were to be abandoned.

Upon taking over these works the Board would proceed at once to sell water to the communities and companies now supplied from the works that were taken over and to any other communities and companies that needed it.

The Wanaque Dam should be completed to the full proposed height but it would probably not be necessary to build a whole new aqueduct for it, as the water from it could be released to the river, (or canal) and taken out at Little Falls. With this done the size of the Little Falls plant should be greatly increased.

Consolidating these sources of supply would permit more water to be obtained than can be obtained from them separately. Stored water in the Wanaque Reservoir would be held back for use during dry periods, and the flow of the river would be used as far as possible when there was enough of it.

The capacity developed by the Wanaque Reservoir, and the increased capacity of the combined system over that of the compon-

ent parts operated separately, amounting to twenty of thirty mgd. and altogether to perhaps 75 mgd., would serve to maintain the supply for a few years, and until larger works were available.

It should be the duty of the Board to furnish water at wholesale to any municipality or water company in the six counties that needed it, but some limits might be necessary in the early years.

To do this it would be necessary for the Board to acquire or lay a system of main pipes. Ultimately this system of main pipes would be comprehensive. At first full use would be made of all existing pipes. Some additional connections would be needed, but it might reasonably be required that water should be passed along by one system to the next; fair compensation for the use of pipes used in transmission being made.

The prices fixed for the sale of water should be such as to make the operations of the Board self-supporting. The prices should not be fixed by long term contract, but should be left open to be determined each year. All takers should have the same rate, but differences in elevation, or in position, or in other conditions of delivery might be taken into account in fixing reasonable differentials. The general scale of prices should be raised or lowered to meet the financial requirements of the Board. In other words, it would be service at cost to all takers.

The burden of the cost of development would be borne in greater measure by those communities and companies who took water from the start. If there were communities and companies whose present works were sufficient, they might not desire to be connected with the system until some future time when water was needed. When they did need water it would be proper that an equitable payment to the general fund should be required from them to represent a proportionate part of capital payments charged off or amortized up to that time.

The Board should at once take up the problem of securing the additional and greater supplies that will be needed. Surveys and borings should be made, and all information collected, and a definite plan proposed, and after discussion adopted. This plan might be the Long Hill plan as now proposed, or with modifications; or the Passaic Great Reservoir plan, or the Raritan plan, or any other plan that should prove best taking into account conditions as they were then found.

After adoption of such a plan the Board should proceed to acquire the necessary sites and to develop the supply in installments,

building these from time to time as the growth of its business requires.

The Board should be authorized to acquire sites in advance of actual need, and to otherwise anticipate future growth, to make sure that the best available sites are reserved for water supply purposes until they are actually needed.

This plan is mainly the plan carried out by the Massachusetts Metropolitan District, which had its beginnings almost thirty years ago, and which has been perhaps the most successful example of work of this kind carried out in this country. The procedure that I have described follows that originally adopted in Massachusetts but includes some modifications that have been found advantageous in practice and added in subsequent years.

Various other means of accomplishing the results might be suggested. Some of them have been used successfully in other cases. None of these appear to be well adapted to present New Jersey conditions, and it is perhaps unnecessary to refer to them further at this time.

It may be added that a strong Board with adequate powers is necessary to cope with such difficult problems as will arise. Half-way measures will not do, and voluntary partnerships do not give a basis for the energetic and effective management necessary to carry out works for a general water supply.

It is a big undertaking and one that is worth doing well.

Respectfully,

Allen Hazen.

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1. Passaic
2. Long Hill
3. Raritan
4. Mullica
ATLANTIC OCEAN
DELAWARE BAY
RARITAN BAY
A. HOEN & CO. BALTIMORE.